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THESIS

EXPLORING A CHROMAKEYED AUGMENTED VIRTUAL ENVIRONMENT FOR VIABILITY AS AN EMBEDDED TRAINING SYSTEM FOR MILITARY HELICOPTERS

by

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June 2004

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Once the military helicopter pilot deploys aboard a naval vessel he leaves behind all training platforms, short of the actual aircraft, that present enough fidelity for him to maintain the highest levels of readiness. To that end, this thesis takes a preliminary step in creating a trainer that places the pilot in an immersive and familiar environment to exercise myriad piloting tasks as faithfully and as rigorously as in actual flight.

The focus of this thesis it to assess the viability of an chromakeyed augmented virtual environment (ChrAVE) trainer embedded into a helicopter for use in maintaining certain perishable skills. Specifically this thesis will address the task of helicopter low-level land navigation.

The ChrAVE was developed to substantiate the viability of having embedded trainers in helicopters. The ChrAVE is comprised of commercial off the shelf (COTS) equipment on a transportable cart.
In determining whether a system such as the ChrAVE is viable as a laboratory for continued training in virtual environment, the opinion of actual pilots that were tasked with realistic workloads was used. Additionally, empirical data was collected and evaluated according to the subject pool's thresholds for acceptable low-level navigation performance.

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EXPLORING A CHROMAKEYED AUGMENTED VIRTUAL ENVIRONMENT FOR VIABILITY AS AN EMBEDDED TRAINING SYSTEM FOR MILITARY HELICOPTERS

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I. INTRODUCTION

A. PROBLEM STATEMENT

Classically, the design of military helicopter simulators has not been user-centered with regard to the embarkation requirements of military pilots. Simply put, simulators that replicate helicopter cockpits are land based and not viable for deployment due in part to their large footprint. While such simulators meet the spectrum of needs of military pilots in garrison, they are rendered useless to pilots once they deploy. In this vein, they are machine-centered designs.

Personal computers, while highly deployable, have also fallen short in meeting the needs of the pilot because the interfaces between human and computer are not realistic; they too are not designed around the user. Personal computer (PC) applications remove the pilot user from his normal environmental interfaces (i.e. the cockpit) and require additional learning on the part of the pilot in order to use the application. For example in the real world a pilot (one of two in the aircraft) may affect a turn to the right by moving the flight controls himself or issuing a command to the other pilot in the aircraft. However, while using a PC based trainer the same turn made using a mouse or keyboard. This is far less intuitive to the trained pilot. In fact, one could argue that even a joystick, which presents a stronger metaphor to the pilot, is just as bad or even worse than a mouse. Granted, some features of PC trainers are not intended to replicate real

world experience, but those that are, should do so with high fidelity and accuracy.

Once the military helicopter pilot deploys aboard a naval vessel en route to destine areas of flight, he leaves behind all training platforms, short of the actual aircraft, that present enough fidelity to the pilot for him to maintain the highest levels of training. To that end, this thesis takes a preliminary step in creating a trainer that places the pilot in an immersive and familiar environment to exercise myriad piloting tasks as faithfully and as rigorously as in actual flight.

B. MOTIVATION

Classically as helicopter pilots prepare for a six-month worldwide deployment aboard ship they spend the six months prior to the deployment honing myriad helicopter piloting and aircrew coordination skills. The process creates a plateau of heightened skills for the entire squadron by the day of departure. However, while en route to destine areas of flight, skills atrophy due to reduced amounts of flight time and the flight regimes available. Adding to skill erosion is the non-availability of shore-based flight simulators while at sea.

Navigation is the chief requisite skill for many aggregate piloting tasks and is therefore a sound choice to begin study of performance in visual flight simulators. The skill of helicopter overland navigation is difficult, if not impossible to maintain while at sea. Visual flight simulators for helicopter pilots are not available aboard ship due in part to space constraints. Additionally,

suitable overland low-level visual helicopter trainers do not meet the needs of the helicopter community.

Current visual systems are poor at rendering an appropriate image to the helicopter pilot. Flight at high altitude is sufficiently portrayed but the earth assumes a distant 2-dimensional posture. It is at low altitude where helicopter pilots navigate, take cover, and mask their exposure to enemy observation and fires. Maintaining these profiles while navigating, specifically associating 3-D terrain images with a 2-D map does not appear possible in present visual systems.

At low-levels visual cues such as optic flow, motion parallax, interposition, etc. have a tremendous impact upon how an environment (real or virtual) is perceived. Accordingly, the head and eye movements of the pilot, which are a form of interaction with the environment, provide vital feedback. In the real world head and eye movements dictate the points of view while the mind produces the visual cue over time (i.e. the cue of motion parallax requires motion over a period of time for the mind to establish or recognize the cue). In a virtual environment (VE), the correct points of view can only be rendered if the system generating the VE accounts for the pilot's head position and orientation. Current simulators do not track the movements of the pilot's head (figure 1); current simulators render views that are dynamic for the moving aircraft but static to the movements of the pilot within that aircraft. Current simulators provide a static point of view for each region or area of view they display. Pilots expecting to 'interact' visually with such systems

are denied the information they seek; although head and eye movements may happen on a subconscious level, the mind is still at work trying to produce visual cues over time. Frustration, anxiety or even cybersickness can result. Often the pilot aborts all attempts to visually interact with the environment; head movements cease and the pilot assumes a television viewing posture. This is a form of negative training.

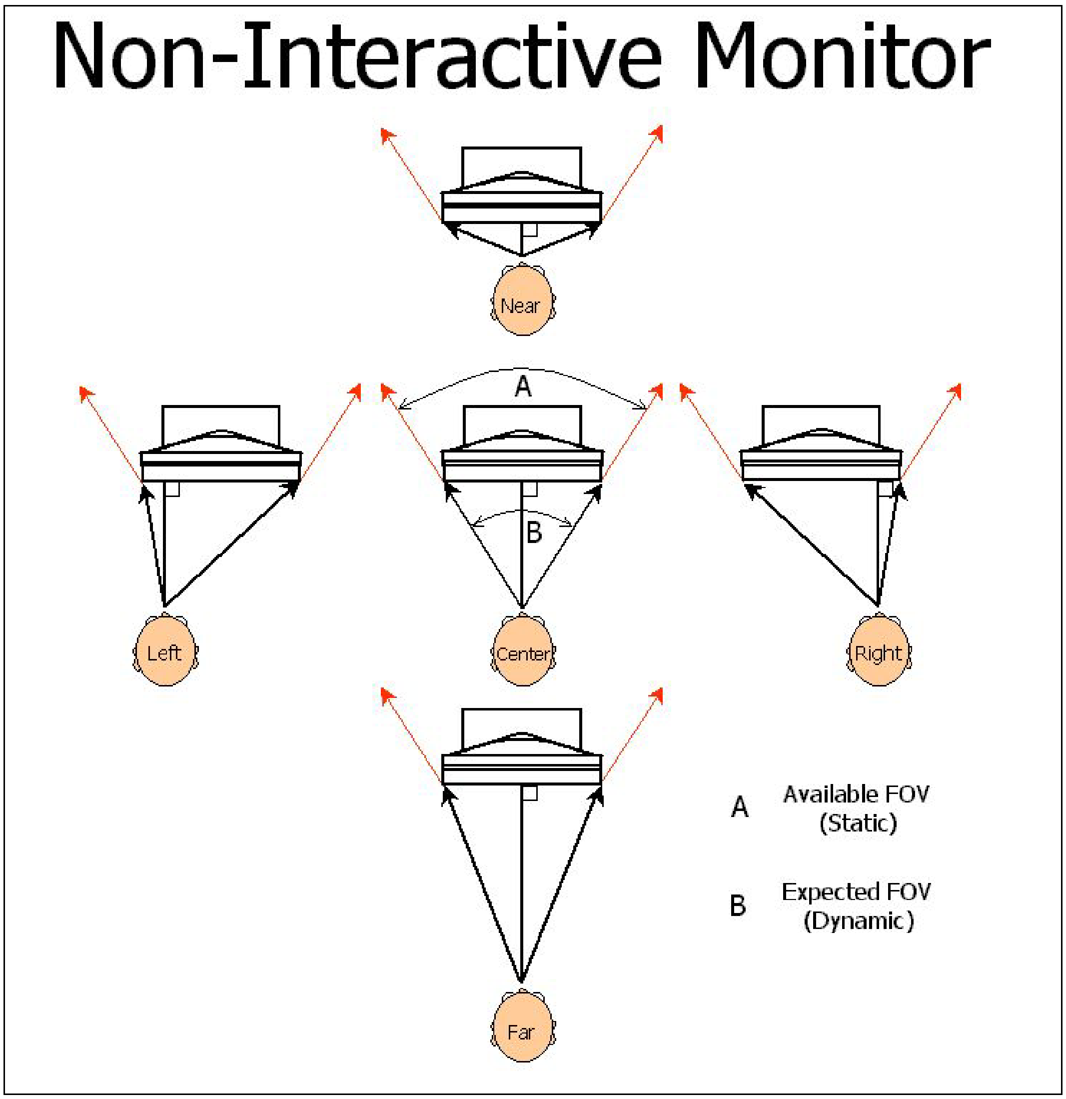

Figure 1.   Viewing a monitor without motion tracking.

Moreover, while pilots are en route to destine areas of flight their resources for interaction are basically limited to conventional 2-D 1:50,000 scale maps. While this may aid in associating relative locations to one another, the ability to visualize being ‘in’ the terrain is drastically limited. It is this visualization that can aid in associating world to map.

It is assumed that in trying to develop a training system for military helicopter pilots, it is important to embrace the entire spectrum of user needs. A system that is easily deployable and presents a cockpit of high fidelity for intuitive use would be most attractive. Logically, a trainer that is embedded into the actual aircraft would likely meet these requirements. Such a training system would take advantage of the actual cockpit, utilize the actual instruments (cyclic and collective) of the human-machine interface as the interface between human and computer, and be as deployable as the actual aircraft with minimal additional equipment footprint.

However, before jumping into full production of embedded trainers, we must first explore the viability of such a trainer. Such exploration requires three basic steps; (1) research into the psychology and potential of training via simulators, (2) the production of a fully operational embedded trainer, and (3) verification of the results of using such a trainer. This thesis is part of step one. A prototype has been developed to explore initial potential of an embedded trainer. If this research proves viable, successive steps may follow.

Such an undertaking is vast when considering the multitude of tasks required to fly a military helicopter in all its possible profiles. For this preliminary research the fundamental task of low-level terrain navigation shall be explored. Navigation is a fundamental underlying function to most every task of helicopter aviation.

C. THESIS OVERVIEW

If embedded trainers are ever to come to fruition, they must first be explored as viable and practicable with regard, first, to user performance (user-centered design), and second, to machine implementation (machine-centered design). In the aforementioned three-step research process, this thesis is part of the first step; implementing a system and running a preliminary experiment.

Present landlocked motion simulators have near-full fidelity of the cockpit. Dimensions of a simulator's cockpit are identical to actual aircraft. Simulator instrument displays provide flight information that is indiscernible from actual aircraft. Flight control response and feedback, while very good, still have room for improvement. Without doubt, simulators can make the greatest gains by improving the interactive graphics of the virtual environment. User-centered designs must embrace the natural way in which a pilot interacts with the environment by creating motion parallax with dynamic head movements.

The best of simulators poorly emulate the feedback required for developing or solely maintaining the skillful dexterity required to manipulate the flight controls of an

actual helicopter. This research shall not try to duplicate such simulators. However, this research shall attempt to focus on the task of low-level navigation, which by its very nature requires no skillful dexterity of the flight controls by the navigating pilot when the duties of aircrew are properly divided. Clearly, if replicating the task of low-level navigation is not viable, then more complex tasks such as faithfully emulating high fidelity in flight control feedback for the maintenance of skilled dexterity will not be viable.

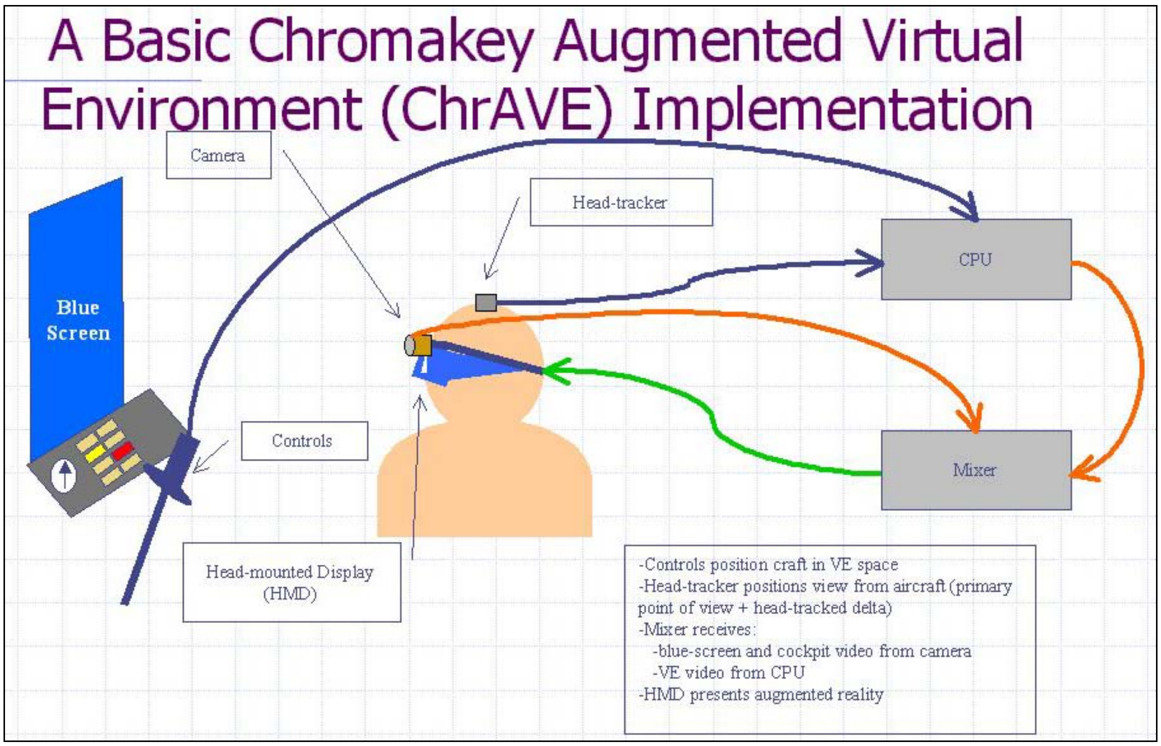

Figure 2. Basic ChrAVE Implementation.

As such, a prototype platform has been devised from which research into the psychology and potential types of training can be launched. This system adopts a generic cockpit environment visually and tactilely while augmenting

it with an inside-out visual representation of virtual terrain. It employs chromakey technology in order to mix the views of the real and virtual worlds, i.e. the user can see himself, his cockpit, and virtual terrain fused together.

If this prototype's development progresses properly, an actual embedded system could assume a small permanent footprint in existing or future aircraft. This system could potentially be used by both ship and land-based deployed helicopter forces. The ChrAVE was developed to substantiate the viability of having embedded trainers in helicopters. The ChrAVE is comprised of commercial off the shelf (COTS) equipment on a transportable cart.

D. RESEARCH QUESTIONS

The basic question of this research is whether or not an embedded trainer is viable in theory, early design, and preliminary experimentation. This system will be considered viable if it is practical to produce, use, and is effective as a training device. These parameters can be difficult to ascertain so the following criteria are offered as determining viability:

1) Opined by experts (qualified pilots) as having value and being practicable. Certainly qualified pilots have valuable opinions about their training needs. This research shall attempt to address their needs as completely as possible. If the collective expert opinion is that such an embedded trainer is not valuable or practicable after use in its present state then it should be redesigned or abandoned. Moreover, since qualified pilots are the end-

user, they can state the likelihood of their willingness to use such a training device, a factor that may prove to be the most valuable indicator that this research is developing favorably. If their collective willingness is low, the system should be redesigned or abandoned.

2) Proven by empirical data as having value and being practicable. If the collective performance of experts having used such an embedded trainer (prototype or full production model) is unsatisfactory, then an embedded trainer is not valuable or practicable in its present state and should be redesigned or abandoned.

3) Acceptable cost of both prototype and full production model. If in pursuit of the user's needs, cost outweighs the benefits of having such a system, it shall not be considered viable in its current state and should be redesigned or abandoned.

4) Vacuously viable. In the absence of finding evidence that proves embedded trainers non-viable, they shall be considered viable.

If ChrAVE development proves viable, it may be an appropriate platform for further experimentation. Much like its cousin the CAVE, the ChrAVE may prove to be a valuable platform from which to launch many human-computer interface (HCI) experiments. The initial design of the ChrAVE was for users performing low-level land navigation. As the scope of military helicopter piloting tasks broaden for future study, shall the ChrAVE prove durable, if not modifiable, for increased demands of such study?

Additionally, developing favorably suggests that the most beneficial interface has been identified and is attainable. To what degree does one need to interact physically with the ‘near’ environment while navigating? Grasping and manipulating objects require optics that allow proper visual representations of the real world and the pilot’s hands. Nearly everything in the cockpit environment is within arm’s reach to the pilot. Should the camera optics provide focus and field of view (FOV) that properly represent the real world within a meter? In Chapter III arguments are presented supporting the interface decisions made for the initial implementation of the ChrAVE. If these assumptions prove off the mark, can they be overcome?

Lastly, embedding the ChrAVE system into the confines of a cockpit may force the development of skills only exercised while flying. Cockpit management skills conform to the ergonomic demands of the cockpit environment and can only be practiced while in such an environment. Might being confined by the physical constraints of a generic cockpit while practicing navigation aid in the act of true real world navigation? Mastering or automating what may appear to be a small component skill such as map folding and management can prove extremely useful when a pilot is applying all his/her mental resources to navigation. Does mentally automating the simple aid in resource management when tasked with the difficult? Alternatively, will attentional demands of component tasks like cockpit management decrease the performance of the principle task of overall navigation?

E. ORGANIZATION OF THIS THESIS

This thesis is organized into the following chapters:

1. Chapter I: Introduction. This chapter includes an introduction to the problem, motivation, and outline for the thesis.

2. Chapter II: Background. This chapter contains pertinent background information including a summary of the work of Sullivan, McLean, Wright, and Vallino, a description of current training methods prior to and upon arrival at destine areas of flight, and a summary of augmented and virtual environments.

3. Chapter III: Approach. This chapter describes the decision process followed to define the goals and features of the training apparatus.

4. Chapter IV: Implementation. This chapter describes how the system was implemented. It contains descriptions and specifications of the hardware components and software employed in the implementation.

5. Chapter V: Methods. This chapter describes experimental setup and execution. It provides necessary information to recreate the experiment.

6. Chapter VI: Results. This chapter contains results of the experiment.

7. Chapter VII: Conclusions. This chapter contains conclusions reached from the testing process.

8. Chapter VIII: Future Work. This chapter describes the research and implementation ideas that the author was unable to perform due to time or technology constraints. Additionally, this chapter suggests new research questions generated by this research.

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II. BACKGROUND

A. THE TASK OF HELICOPTER TERRAIN NAVIGATION

From the early days of flight school each pilot is implored to prioritize competing tasks in accordance with the ‘axiom of 8s’, aviate, navigate, and communicate. Aviating is the first order of business and requires obstacle avoidance and skillful flight control dexterity as well as employing proper decision making with regard to flight profiles and immediate actions during emergencies. Failure to aviate can be fatal. Navigation is attended to when aviation is under control. It requires less skillful dexterity and is more on the order of planning and controlling the course and position of the aircraft. Lastly, communication shall be attended to. While simple in procedure, communication can rob mental resources from aviating and navigating, thereby creating an environment that requires correction. Failure to effectively communicate is unlikely to be fatal in and of itself, but attending to communication while holding aviation and navigation at bay can promote their failure.

Successful helicopter terrain navigation is the product of cohesive aircrew teamwork. Each member of the aircrew has specific duties and responsibilities. The pilot at the controls (PAC) and the pilot not at the controls (PNAC) or navigator comprise the main aircrew component. Depending on the type of aircraft additional aircrew may be aboard and share in the duties of navigation; however this thesis will focus exclusively on PNAC, the navigator.

1. Types of Flight Profiles

This thesis is primarily concerned with flight and navigation at or below 200 feet above ground level (AGL). The Assault Support Helicopter Tactical Manual (CNO, 1992) divides this area of flight into three categories.

> **a. Low Level Flight:** Flight conducted at a selected altitude at which detection and observation of the aircraft or of the points which, or to which, it is flying are avoided or minimized. The flight route is pre-selected, generally a straight line and is flown at a constant airspeed and indicated altitude.
>
> **b. Contour Flight:** Low altitude that conforms generally and in proximity to the contours of the Earth’s surface. It takes advantage of available cover and concealment to avoid an enemy’s observation or detection of the aircraft or its departure and landing. It is characterized by varying of airspeed and altitude as vegetation and obstacles dictate.
>
> **c. Nap of the Earth (NOE):** Flight as close to the Earth’s surface as vegetation and obstacles permit while generally following the contours of the Earth’s surface. Altitudes and airspeeds are selected based on weather, lighting conditions, and enemy situation. The pilot preplans a broad corridor of operation based on known terrain features with a longitudinal axis pointing towards his objective, but in flight he uses a weaving and devious route within the corridor and oriented along the axis to take advantage of the cover and concealment afforded by terrain, vegetation, and man-made features.

Depending on many factors, migration from one flight profile to another can be instantaneous or even continuous. This thesis will primarily deal with low level and contour flight; however the task of navigation during the experiment will avoid tactical flight and shall embrace

navigating along the intended route of flight while hitting the intended checkpoints.

2. Division of Duties

a. The Pilot at the Controls (PAC)

The flying pilot is responsible for actual manipulation of the controls, avoiding obstacles, and reporting key terrain and landmarks to the non-flying pilot utilizing standard terrain feature terminology. His focus is primarily outside the aircraft.

b. The Navigator / the Pilot Not at the Controls (PNAC) / the Observer

The pilot not at the controls is referred to by different titles amongst the various references; for the purposes of this thesis the title navigator will apply to the PNAC. The tasks and responsibilities of the PNAC are of particular interest to this thesis. The ChrAVE's overall system goals are tailored to the needs of the navigator and each task has been faithfully emulated for evaluation in the experiment phase. The duties and responsibilities of the navigator are:

- Navigating from waypoint to waypoint on the intended route.
- Maintaining orientation / Monitoring location.
  - Associate 3-D terrain with the 2-D map representation.
  - Utilize timing as a redundant means of monitoring location.
  - Identify/utilizing key terrain features.

        - Checking features.
        - Channeling Features.
        - Limiting Features.
- Provide directional voice commands to the flying pilot.
    - Standard directional voice commands.
    - Standard terrain feature terminology.
- Monitor/manage radios.
- Monitor cockpit instruments.
- Manage navigational equipment.

B. LIMITATIONS OF CURRENT FLIGHT TRAINING METHODS

Limitations of current training while land based methods are mundane except when considering the 1) expense of training via actual flight (both monetarily and in maintenance man-hours) or 2) access to immersive training and rehearsal tools. Standard training techniques employ the following:

- Trainees performing background study of the procedure or flight profile
- Trainees attain rote memorization of the procedure
- Pre-flight brief detailing the procedure or flight profile
- Instructor demonstration of the procedure or flight profile in flight

- Trainee execution of a procedure or flight profile in flight
- Post-flight brief detailing the trainee's performance

When training is done in this manner via actual flight the instructor has competing interests, i.e. maintaining situational awareness of all the parameters of the aircraft and observing the trainee in total (airmanship and the bearing). The instructor can concentrate on observing the trainee much more in simulated flight. If the simulation is presented to the trainee with high fidelity, the trainee will be mentally taxed in a realistic manner and weaknesses will surface. This is the case in present full-motion instrument flight rules (IFR) simulators; trainees monitoring and answering radio calls while monitoring instruments, applying flight control corrections, ignoring their own proprioceptive system, and maintaining their location on an approach plate often demonstrate manifestations of being overloaded in a number of ways. Breakdowns in airmanship, fixating on instruments, unanswered or unacknowledged radio calls, loss of situational awareness, faulty cockpit management skills, anxiety, agitation, and belligerence are all signs that a trainee has encountered a personal training limitation. In actual flight, baring airmanship, these manifestations can be difficult to observe. The use of helmets and visors can compound this difficulty.

Identifying weaknesses in the trainee's performance is only half the battle. Showing the trainee the error of their ways and then suggesting alternate techniques that

tend to be more successful is the remaining part. It is thought that automating some techniques provides more mental resources for the remaining competing interests.

Current training techniques of low-level helicopter navigation in simulators do not force the trainee to perform the mental calisthenics necessary in actual flight. Furthermore, current flight rehearsal systems do not place the user in an immersive or compelling environment for critical decision-making.

Lastly, collaborative flight training tools, meaning flights of two or more aircrews, simply do not exist without actual flight. Traditionally, a land-based helicopter squadron only has a single simulation resource and if more than one does exists, they are not networked for collaborative flight.

C. LESSONS LEARNED FROM RELATED VIRTUAL ENVIRONMENT APPLICATIONS

It is clear that a deployable trainer must have a small footprint. Desktop computer implementations have been attempted with varied results. More importantly, these implementations have shed light on the value of certain features incorporated. It is beneficial to leverage these valuable features into any new implementation. This statement remains true even if a desktop computer implementation is not carried on.

1. Summary of Sullivan's Research

Sullivan's work identified helicopter pilots as principle subjects in an open terrain navigation

experiment. His desktop computer system employed four 19-inch monitors, each with a 640 x 480 resolution. The four monitors were set up in a semi-circular array configuration that provided a wide aggregate 129° field of view (FOV). However, the aggregate FOV was interrupted by monitor borders. Center gaze for a user fell upon the center set of monitor borders. Sullivan over came this by offsetting the viewing frustum 32° to the right. This off-axis configuration (Figure 3) allowed for the user's center gaze to be coincident with the center of the third monitor. In effect, the monitor array mirrors the windscreen array on the left side of an actual aircraft since navigation duties are normally performed from the left seat in the SH-60F/H.

Figure 3. From (Sullivan, 1998). Four monitor off-axis array.

Sullivan saw value in employing a large display capability. Additionally, Sullivan noted the aggregate FOVs of actual aircraft versus motion based simulators, TOPSCENE (a single monitor application), and a three-monitor configuration of his system (Figures 4, 5, & 6).

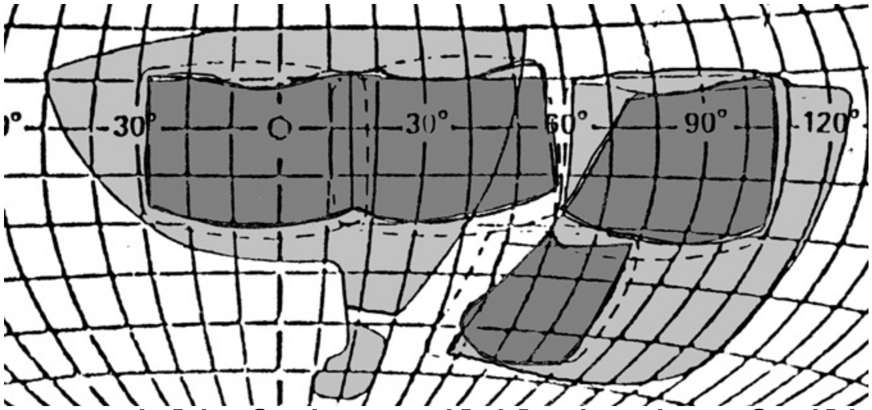

Figure 4. Field of view available in aircraft (light gray) compared to motion-based trainer (dark gray). Adapted from (Sikorsky, 1989).

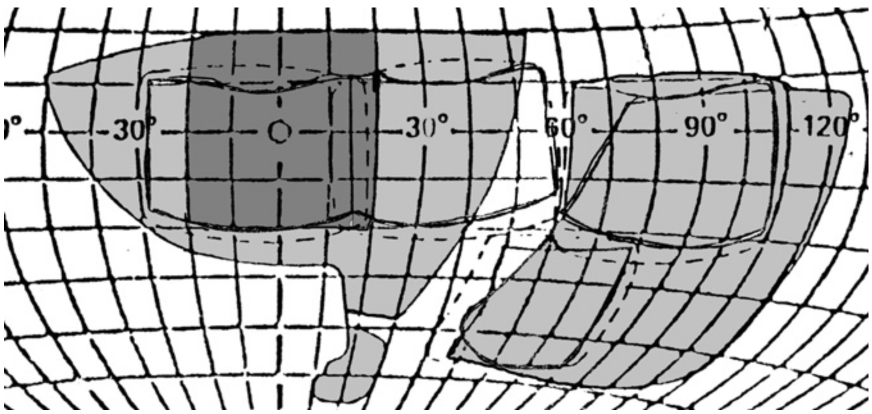

Figure 5. Field of view available in SH-60F (light gray) compared to TOPSCENE (dark gray). Adapted from (Sikorsky, 1989).

Large display capabilities provide two important concepts worth noting. The first is periphery views. When there is a large aggregate FOV, the portion of the display not being directly looked at moves into the periphery. Periphery views not only reflect views available in the real world, they also provide significant information to a pilot for assessing relative motion of the aircraft. Narrow FOV displays allow little, if any, periphery view.

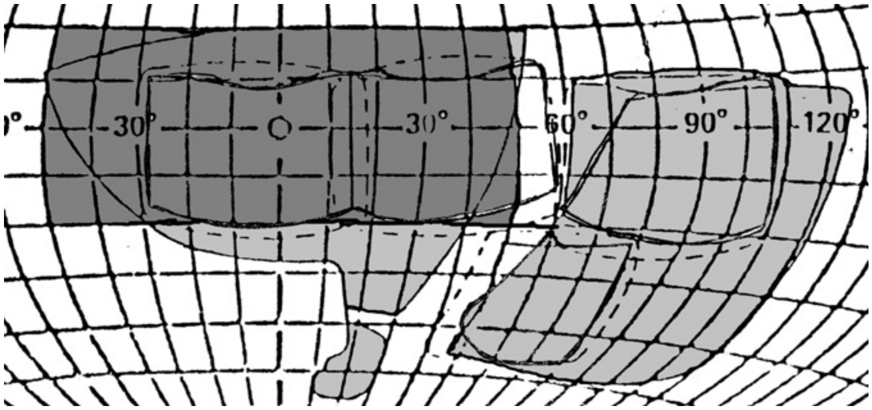

Figure 6. Field of view possible using a three-screen configuration (dark gray) compared to field of view available in SH-60F (light gray). Adapted from (Sikorsky, 1989).

The second concept is that of independent directions of gaze and travel. In single monitor implementations, such as TOPSCENE, the monitor presents a view married to the twelve o'clock position of the aircraft. If the pilot wants to view terrain that is on the aircraft's nine o'clock, the pilot must maneuver the aircraft so that the terrain desired enters the viewing frustum of the aircraft's twelve o'clock. However, when the aggregate FOV is substantial, the pilot may be able to view terrain in the nine o'clock position while maintaining flight in another direction. Sullivan noted that larger FOV display allows for a longer period of time to view a terrain feature without changing course (Figure 7).

These two concepts aid in the total immersion perceived buy the user. They allow the pilot to interact with the VE in a more natural way and they allow the task of low-level land navigation to be more realistic.

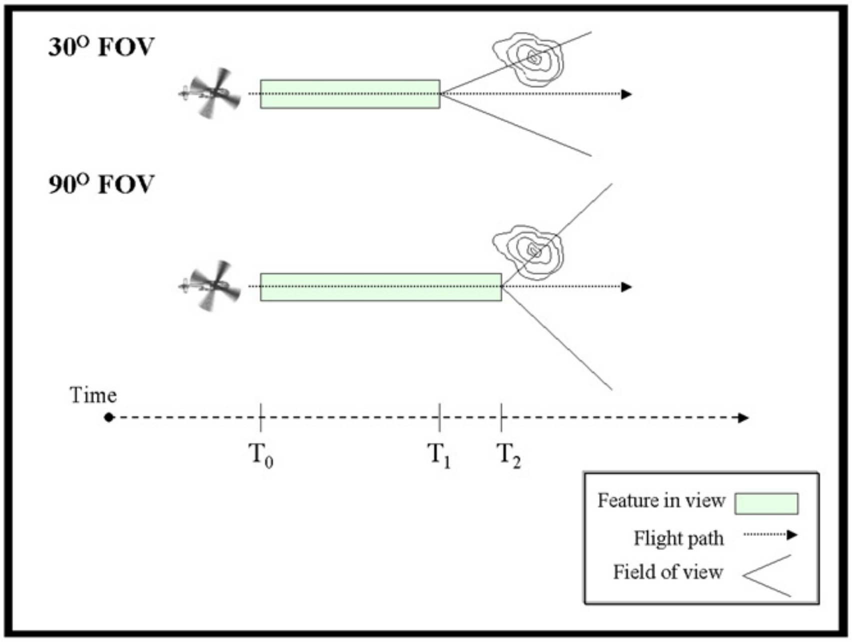

Figure 7. From (Sullivan, 1998). Time available to view a terrain feature based on FOV.

2. Summary of McLean's Research

McLean continued Sullivan's research with emphasis on determining if a second-generation system could be used to train the tasks of map interpretation and terrain association. McLean's implementation employed a three-monitor array display. This research yielded proof that the system was successful in training the tasks of map interpretation and terrain association, however, McLean concluded that the system could not be used for testing for the tasks of navigation due to lack of any correlation between performance using McLean's implementation and actual flight.

Low task realism and system fidelity may have played a roll in these outcomes. McLean's implementation was effectively a part task trainer for navigation.

Specifically, McLean’s implementation was strictly effective in training map interpretation and terrain association without the other additional competing interests involved in actual flight.

Although Sullivan and McLean made no attempt to present their systems as cockpit clones, interface metaphors do exist. In fact, flight control manipulation violates the premise of an aircrew’s division of duties for the navigating pilot.

3. Summary of Wright’s Research

Wright recognized that “helicopter missions are never defined as ‘…successful navigation to and return from a location.’ Navigation, in and of itself, is not the mission – it is merely a skill that all helicopter pilots are expected to master in order to perform their duties as pilots.” Additionally, Wright notes that the inherent expense and unforgiving nature of helicopter flight, makes it a prime candidate for innovative training techniques such as virtual three-dimensional (3-D) fly-throughs. His research sought ways to assist pilots in planning routes for and navigating in an urban environment using 3-D graphical displays and virtual fly-through computer models. Furthermore, Wright sought to supply the user with the graphical fidelity necessary to accomplish the task in order to reduce the computational strain on the computer system.

Wright quotes Thorndyke & Golden (1983) on the three hierarchical levels of information concerned with navigation as it pertains to urban terrain.

- *Landmark knowledge: information about the visual details of specific locations in the environment. It is memory for notable perceptual features such as uniquely shaped buildings.*
- *Procedural knowledge (route knowledge): information about the sequence of action required to follow a particular route. Procedural knowledge is built by connecting isolated bits of landmark knowledge into lager, more complex structures.*
- *Survey knowledge: configurationally or topological information. Objects locations and inter-object distances are encoded in terms of geocentric, fixed, and frame of reference. A geocentric frame of reference is a global, map-like view, while an egocentric frame of reference is a first-person, ground-view relative to the observer.*

Wright was mostly concerned with providing enough visual fidelity for pilots flying into a given urban area of flight for the first time. For example, first time flight into the Washington D.C. area may include graphical depictions of the mall, monuments, and auspicious governmental buildings. That may provide enough fidelity to determine direction of flight or provide reference points for more detailed navigation.

These levels of navigational information may be applied abstractly to navigation or wayfinding other than urban flight. Note that while flight in feature deprived areas such as at sea, snow-scapes, and desert-scapes can be more difficult for determining precise location, general location and heading can be relatively simple to determine using a minimum or perhaps only two or three reference points (key terrain features).

Figure 8. From (Wright, 2000). Aerial Photo vs. Virtual Views of Tysons Corner, Virginia.

Wright attempts to exhibit notable reference points in and urban environment while suppressing the anonymous reference points (noise). On a metaphoric level this is equivalent to depicting the interesting tree(s) with high detail, while suppressing the detail (and polygons) of the common trees of the forest.

D. SUMMARY OF CHROMAKEY TECHNOLOGY

Chromakey technology has been in existence for a number of years in hardware but has been making strides more recently in software. This technology identifies a key color, often blue or green, that is found in a foreground scene and is replaced with the corresponding pixel from a background scene. A single composite scene is the result. The weather report on the nightly news is a prime example of this technology being demonstrated in real time.

Adaptations that are more complicated also exist in our daily lives. Figure 8 displays a chromakey technique that requires registration so that the placement of the virtual or augmented information appears properly aligned and fused with the main scene. Note the obscuration effect the player has on the virtual yellow line. Also, note that there are many shades of green, the key color, on the playing surface. A wide key color range is utilized in this implementation and it is adjusted continually for changes in the videoing environment. However, if the player’s uniforms were also green, the augmented yellow line may obscure a portion of the player. Additionally, the

stadium must be mapped out and modeled and each camera’s placement must be calibrated.

Figure 9. From (Azuma, 2001). Obscuration and fusion of a first down line with moving coverage of the play.

E. AUGMENTED REALITY

1. Summary of Vallino’s Research

Vallino quotes Aukstakalnis and Blatner in defining Virtual Reality (VR) as “a computer generated, interactive, three-dimensional environment in which a person is immersed.” Vallino provides amplifying remarks by dissecting the term into three parts.

> First, this virtual environment is a computer-generated three-dimensional scene that requires high performance computer graphics to provide an adequate level of realism. The second point is that the virtual world is interactive. A user requires real-time response from the system to interact with it in an effective manner. The last point is that the user is immersed in this virtual environment.

Vallino states that “Augmented [R]ealty [AR] is the merging of synthetic sensory information into a user’s perception of a real environment.” (Vallino, 1998) In order to distinguish between VR and AR he refers to Milgram’s reality-virtuality continuum (figure 8).

Figure 10. From (Azuma, 2001). Milgram’s Reality-Virtuality Continuum.

While arguments as to how an implementation such as the ChrAVE should be categorized using this continuum may arise, it should be noted that the participation of the real world and virtual world varies during execution of the many part-tasks performed while navigating. It suffices to say that the ChrAVE is a mixed reality system that augments a virtual environment (a terrain model) with the real world (a cockpit).

Vallino creates an overview of the many types of AR implementations. His work’s main thrust is that the AR interface can be made interactive by a form first person manipulation. He uses affine representations to define a global coordinate system for the induction of virtual objects. Manipulation of these fiducial targets directly

affects the appearance of the virtual objects in the scene with regard to position and orientation (figure 9).

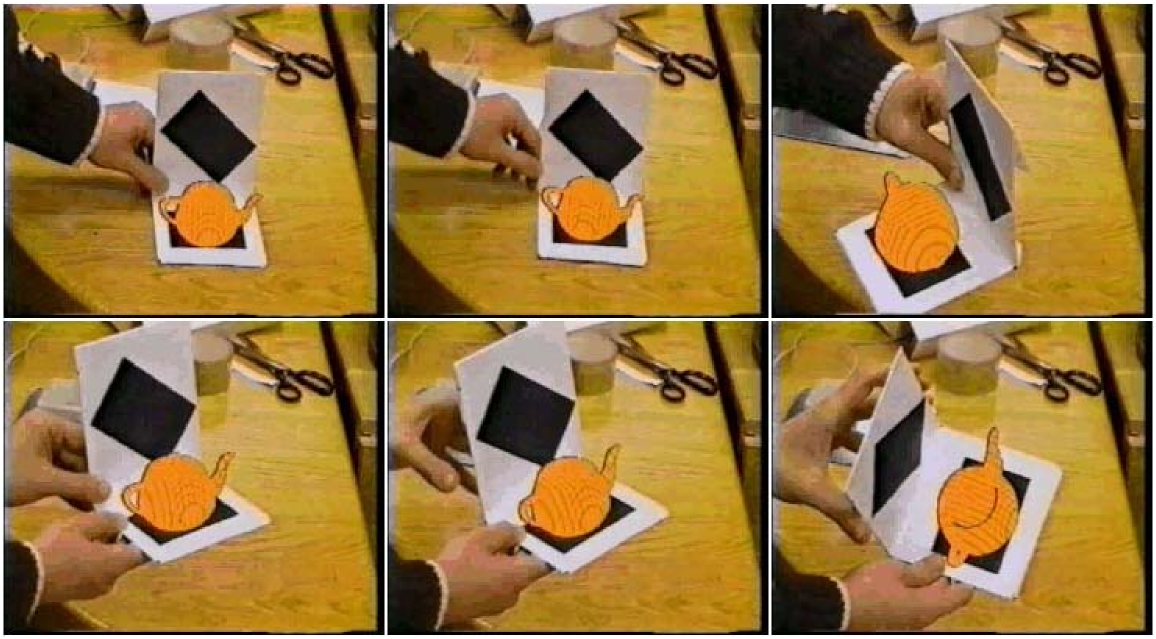

Figure 11. From (Vallino, 1998). Manipulating Virtual Objects.

Vallino remarks on the necessity of fusion between real and virtual worlds for immersion and presence to take place in the mind of the user. Fusion requires global coordinate system registration so that virtual objects can be appropriately rendered in the augmented scene. There are a number of ways to provide the computer with this information. The two basic ways are 1) for fiducials to be optically detected in the real world scene and then calculate the position and orientation of the virtual object, or 2) for an input device such as a motion detector or articulated arm to provide direct position and orientation for the virtual.

Vallino's implementations augmented the scene with virtual objects completely within a single CPU. As a result, latency can be a factor in properly rendering the scene. In this type of augmentation, the real world is the background while the virtual world is the foreground. Contrarily, the ChrAVE invokes off-chip chromakey hardware that replaces the key color (blue) in the real world scene with the augmented scene. This reduces the CPU load in rendering the final scene. In chromakey augmentation, the real world is the foreground while the virtual world is the background.

2. Summary of Southwest Research Institute's (SwRI) Applications

The Southwest Research Institute (SwRI) has implemented a number of trainers demonstrating camera tracked chromakey technology. The composite scenes presented to the users exhibit scenes where real world objects are within a virtual world. The real world is the foreground while the virtual world is the background.

In the infantry implementation (figure 12) the user wears a head-mounted display (HMD) that is tracked for orientation and position. The HMD is equipped with a camera and microphone (figure 11). The user is placed in a chromakey blue curtained chamber. The composite image presented to the user contains his view of all real world objects with a virtual environment invoked as the background. In this case the VE is dynamic and contains combatants the user must engage. The user's model M-16 is also equipped with a tracking device and is fitted with a

recoil mechanism. Pointing and shooting the weapon registers shots in the VE. Locomotion is provided by a pressure plate placed at the users feet. The user wears a third motion tracker at the small of the back to provide directional orientation to the system.

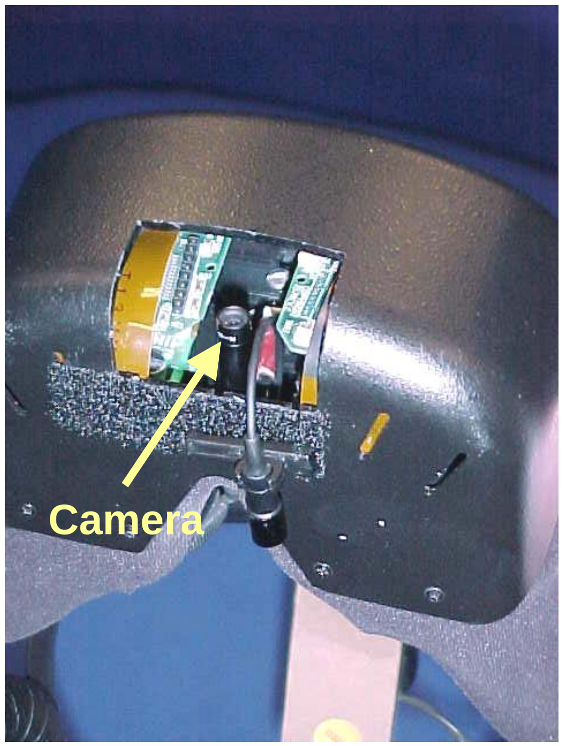

Figure 12. SwRI's Camera placement on a modified V8 HMD.

Since the ‘eyes’ of the user are provided by a single static mounted fixed-focus camera, aiming the weapon using the sites in a natural manner is not possible; the weapon is best used when fired from the hip. Additionally, matching the FOV of the camera and the FOV of the HMD while allowing focus of all real world objects prove to be difficult; the view of ones hand in the HMD appears larger than normal. As a result, hand-eye coordination with real

world objects is affected. Performing immediate action for a stoppage in the weapon is slow and clumsy when looking at the weapon, however, if the user is familiar with the procedure it can be performed quickly with the eyes closed. To some degree this awkwardness can be reduced with extended exposure to the HMD.

Figure 13. SwRI’s Infantry Chromakey Implementation.

In the High Mobility Multipurpose Wheeled Vehicle (HMMWV) implementation two users can use the system. A driver position and M-60 machine-gunner position are equipped with similar HMD assemblies noted above. The driver interacts with the VE by intuitively driving through it; the steering wheel, pedals and shifter are input devices to the computer system. Meanwhile the machine gunner’s M-16 is tracked and fitted with a recoil mechanism that activates when fired. Once again, the VE contains enemy combatants.

The desired emergent behavior is that the driver and machine-gunner exercise sound crew coordination and communication techniques to overcome the enemy.

Figure 14. SwRI's M-60 mounted HMMWV Chromakey implementation.

While the system does not infringe on the hand-eye coordination of the driver, it does impair the gunner in some respects. Driving does not require visually referencing the steering wheel, pedals, and shifter. This system assumes a driver can drive without looking once seated; occasional glances are accepted. However, the gunner requires a higher degree of hand-eye coordination when manipulating and reloading the weapon, which can occur often in is such a scenario. As in the infantry implementation, sited marksmanship is not possible. But with a machinegun single shots are seldom necessary. Instead, the HMMWV-mounted weapon is fired and the impacts are walked onto the target as in the real world.

Vallino’s implementations augmented the scene with virtual objects while relying on CPU power. As a result, latency can be a factor in properly rendering the scene. In this type of augmentation, the real world is the

background while the virtual world is the foreground. Contrarily, SwRI’s implementations utilize off-chip chromakey hardware to create the composite. This reduces the CPU load in rendering the final scene, which minimizes latency, jitter, and other fusion misgivings. In chromakey augmentation, the real world is the foreground while the virtual world is the background. Over time Moore’s law will allow Vallino’s implementations to latent-free, however, sighting the entire fiducial in a scene continually may not be possible do to head movements and obscurations. This would result in augmentation interruption. Therefore the ChrAVE will utilize an implementation similar to SwRI’s.

III. APPROACH

A. OVERALL SYSTEM GOALS

The overall goal of the ChrAVE prototype system is twofold:

1) To place the subject in an immersive and familiar environment, true in first person fidelity with as few physically imposed distractions as possible.

2) To exercise the task of navigation as faithfully and rigorously as the task is in the real world.

B. DISPLAY DEVICE DECISIONS

1. Head-Mounted Display (HMD)

In selecting displays one needs to consider the practical and technical limitations of available display hardware, as well as the user's requirements and the specific tasks in which the display device will be used. The trade-off between the display's FOV and spatial resolution is a crucial one (Melzer & Moffitt, 1997). Sullivan addressed FOV with regard to a single monitor or an array of monitors where the direction of gaze is dependent a) on the region of view the monitor is intended to display and 2) the of direction of flight. All FOVs have a coincident point of view or a sweet spot from which viewing is optimal for the user. In other words, a monitor provides a FOV base off the direction of flight. Pilots wanting to inspect specific terrain have to fly in such a manner as to place the desired terrain in a region of view. While an HMD provides a constant angular FOV, with the use

of head-tracking the pilot can dynamically affect the gaze independent of the direction of flight. This is regarded as a dynamic point of view. Head movements would provide all possible views out of the cockpit that the real world provides. It would logically be assumed that a head-tracked HMD would provide a total FOV equal to that of the light gray regions in figures 4, 5, and 6.

Additionally, HMDs tend to provide a more immersive environment for the user. Considering military helicopter pilots are accustom to night vision goggles (NVGs) and their similarity to HMDs, employing an HMD as the primary visual device is the logical choice.

2. Camera & Lens

Although binocular vision is used in NVGs, binocular vision in the ChrAVE would require duplication of most of the signal processing hardware. Although binocular vision may prove beneficial in the user's active interaction with and manipulation of objects in the real world, such gains are expected to be minimal. Since stereopsis is less effective beyond 10 meters (Melzer & Moffitt, 1997), rendering the VE stereoscopically to the user would also provide little to no advantage for VE viewing. Considering the early stage of this research and the expected low gains in fidelity of a binocular/stereoscopic system, monocular vision shall be employed in the ChrAVE.

The camera will largely comply with two criteria, overall system integration and be as high-end as budgetary limits will provide. Overall system integration of the camera is concerned with 1) lens availability and swap-

ability and 2) the video signal requirements that must be provided to the remaining components of the system. An industry standard mount is most attractive because it yields relatively high numbers of potential lenses.

Lens selection is based off many factors including visual requirements such as first-order parameters (focal length, FOV, and f-number), performance parameters (emphasizing limits of distortion), and other parameters (such as size, weight, shape, and zoom). “Commercial optics are often useful at the early (budget strapped) prototype stage where ‘proof-of-principal’ demonstration of a particular application is important to ensure project survival (Fischer, Couture, & McGuigan, 2002). At this early stage of research and considering the research of SwRI, it appears that of the shelf optics that optimally meet the following parameters shall be considered:

1) A depth of field within arms reach that renders objects in focus and appropriate in perceived size. Depth of field depends on three factors, with the size of the lens opening, the distance of the objects focused on, and the focal length of the lens.

2) The lens should provide a FOV that matches the FOV limits of the HMD.

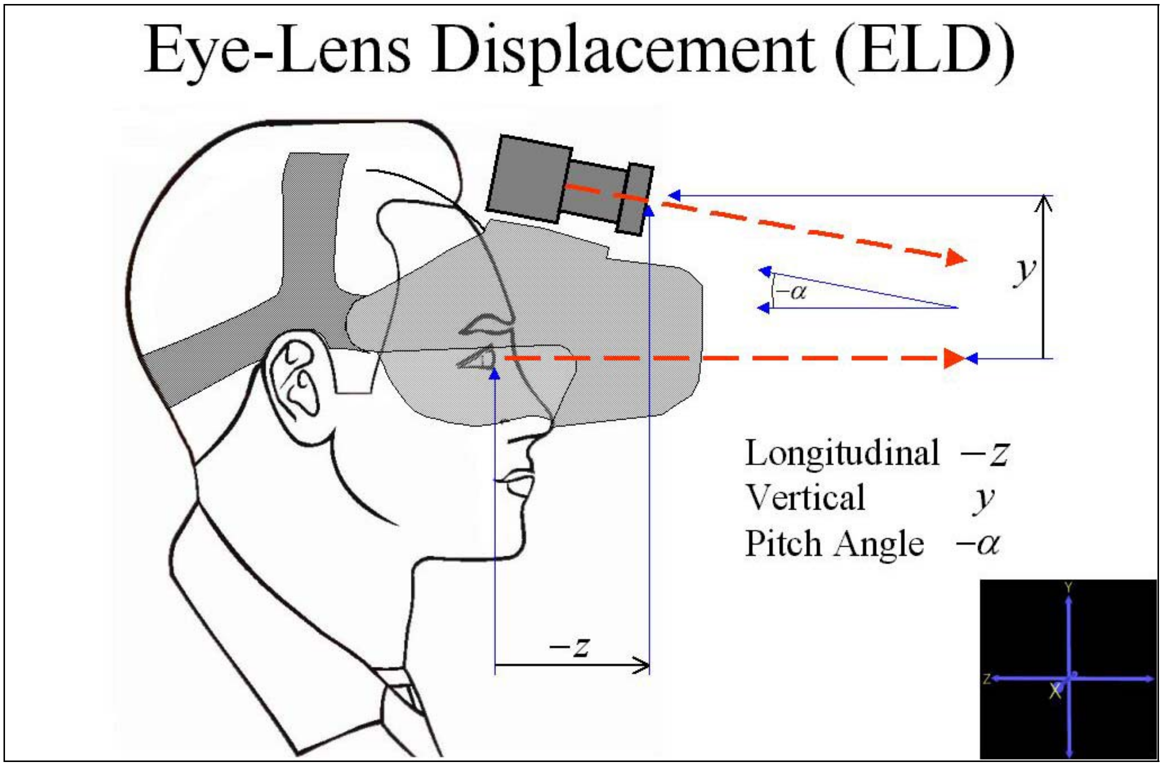

Figure 15. Eye-Lens Displacement.

3) Size, weight, and shape are considered because the camera and lens will be mounted onto the HMD. Size and shape will dictate possible locations to mount the camera and lens onto the HMD. It is desire for the user's eyes and the camera to share the same optical path. Since that is rather complicated for this early research, minimizing the collective separation of these paths shall be emphasized. The camera and lens must be mounted in such a manner as to minimize the displacement of the camera to the user's eyes yet still converge on an acceptable place in front of the face so the user can easily refer to their hands. Parallel optical paths would have the user reaching too high or low or initiating excessive head movements to

see their hands. This eye to lens displacement (ELD) represents both a rotation and translation between the user's and camera's optical path origin (figure 14). ELD is expected to affect the user's active interaction with and manipulation of objects in the real world environment. The weight and balance of the HMD upon the user's head effects both rate of fatigue and the user's interactive information gathering. The entire head assembly will mimic the physical demands already placed on helicopter pilots employing NVGs.

Although methods exist that can minimize ELD to near zero by employing cameras and mirrors assemblies, such methods have not be explored due to their expected sophistication, fragility, expense, and the aforementioned size and weight issues. The advantages that such methods may have would be rather interesting to study in follow-on work. That said, Wurpts notes that Biocca and Rolland "found that the displacement of the camera position from the eyepoint can cause an inter-sensory conflict between the human visual and kinetic senses.' This conflict increases the difficulty that users experience when interacting with real objects while immersed in the virtual environment."

C. MOTION TRACKER DECISIONS

A motion tracker that provides 6-DOF, position, and orientation is determined to be required, although one could argue that only orientation is essential since head movements in the near field would be notice via the camera's view of the real world, and that the far field

would simply not be noticed because the virtual terrain viewed is too far away to pick up any discernable angular difference. As needed, location tracking can be turned off only allowing for orientation. A line of site motion tracking system may be vulnerable to the movements of the user, therefore, position detection with inertial redundancy is desired. Also attractive is a tracking device that imposes minimal movement constrictions on the user.

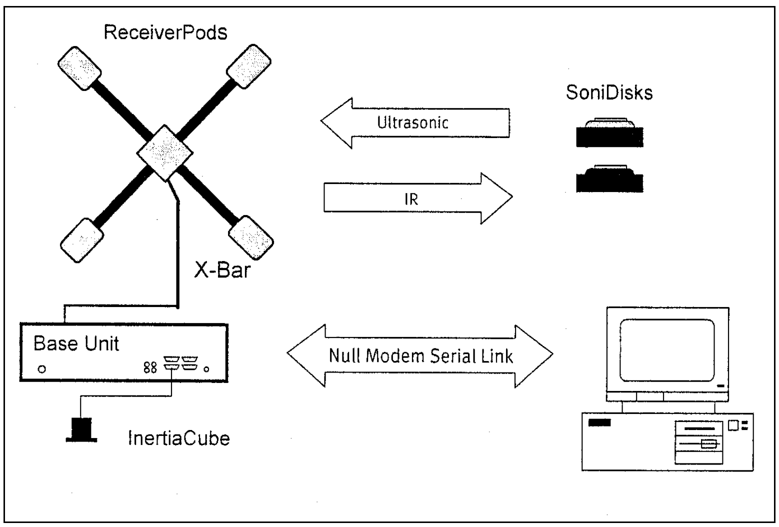

Figure 16. Modified from (InterSense, 1999) IS-600 Mark 2 block diagram.

Figure 17. From (InterSense, 2001) IS-600 Mark 2

D. LOCOMOTION DEVICE DECISIONS

During flight, the navigating pilot will direct the flight of the aircraft by giving appropriate voice commands to the pilot at the controls (the proctor). See Appendix B, page 5 of the ChrAVE Experiment Questionnaire for a list of navigational commands available to the navigator. This behavior is identical to that utilized in actual flight, therefore, no learning curve exists for the subject.

Such navigational behavior can be characterized as active in terms of mental activity required to effectively determine position, course, and the next verbal command while navigating, but passive in terms of actually manipulating the flight controls. Ironically, the navigator is generally mentally more ‘active’ than the pilot at the controls. While the pilot at the controls has

a view of the outside world, he may not know where he is in that world. Contrarily, the navigator actively compares the map to the real world. Since the navigator has the map as a reference to all the terrain in the area of flight it follows that he is more active in the investigation of that terrain. In fact, while it is a crew coordination task to maintain situational awareness and knowledge of the aircraft's whereabouts at all times, it is the navigator, who through use of the map and the outside world challenges the certainty of the aircraft's place in space. Successful navigation requires vigilant uncertainty management, the degree to which uncertainty is minimized and considered acceptable.

Figure 18 suggests that being both the PAC and the navigator would more heavily task a single pilot than employing a division of duties amongst the two pilots.

Because conversational, real world voice commands are to be used, computer recognized voice commands were abandoned; there are simply too many verbal ways to direct the same activity. Voice commands recognized by computer require that they be precisely structured and miscommunication (rate of error) would be far too high to be reliable with the complexity of phrases and utterances made by the navigating pilot.

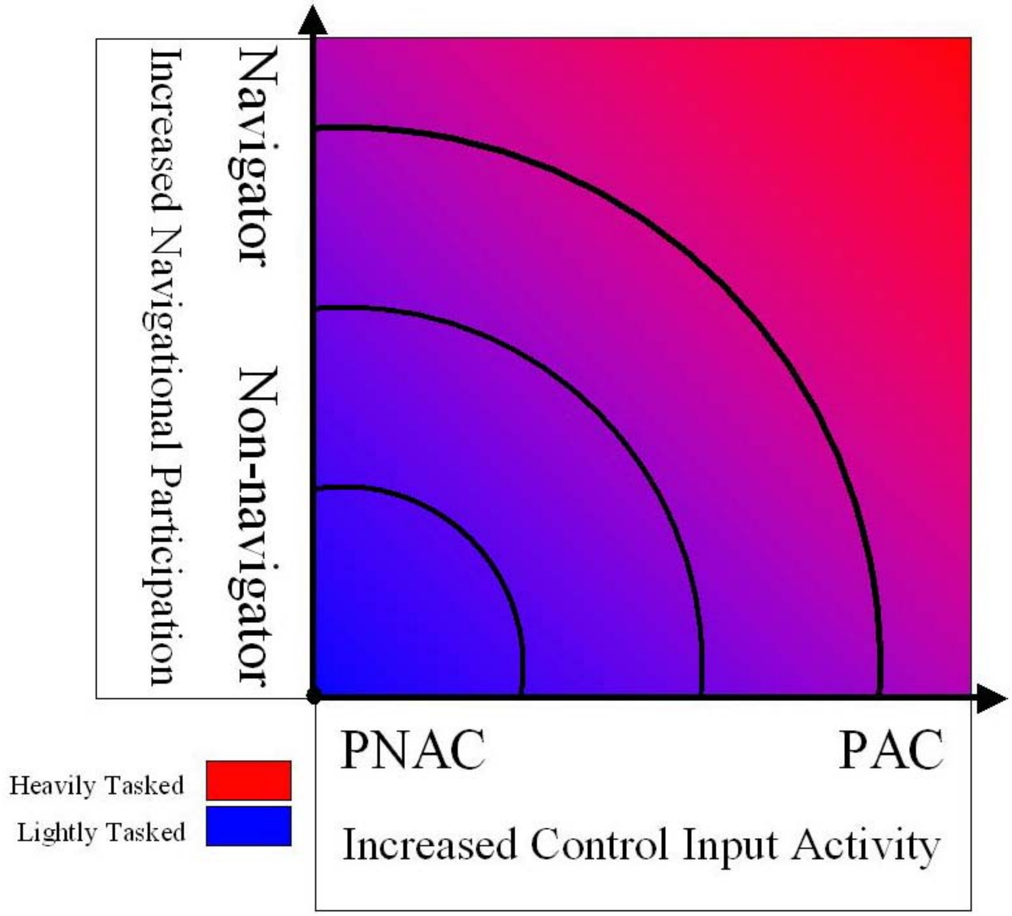

Figure 18. Passive Active Matrix.

Actual manipulation of the ChrAVE's flight model will be done by the proctor via keyboard. Each basic command will be accomplished by providing the appropriate corresponding keystroke. Utilizing canned keystrokes instead of a joystick type of input device ensures that each subject participating in the experiment receives identical response to their commands. For example if a subject calls for a right turn to 9 o'clock, a keystroke initiates that turn. Each turn is identical in terms of roll in/out acceleration and accuracy.

E. MOCK COCKPIT DECISIONS

The ChrAVE primitively mocks the right half of a side-by-side dual piloted helicopter. It is meant to be rather generic to all helicopter communities. It employs a semi-surrounding wall, roof and windscreen panes to provide immersive visual aesthetics. They are designed to be realistic obstacles that cause real world obscurations and can be referenced to determine rate of movement and attitude with regard to the viewable virtual world. These structures impede line of sight and force head movement during the task of navigation.

An instrument panel includes an airspeed indicator, an attitude indicator, an altimeter indicating height above mean sea level (MSL), a turn rate indicator, a compass, and a vertical speed indicator (VSI).

The flight controls, a cyclic, a collective and rudder pedals are also employed to be normal helicopter obstacles for the navigating pilot since a navigating pilot does not use these input devices while navigating.

F. FEEDBACK

The navigator, through use of the HMD, will have a merged view of the real world and the virtual world. The real world shall consist of the mock cockpit, objects within that cockpit, and the navigators view of himself. The virtual world shall consist of a computer-generated world complete with images of terrain, buildings, aircraft, ground vehicles and atmospheric effects for the specified area of flight. Head movements will affect viewpoint changes in both the real and virtual worlds. Head

movements will allow natural interaction/investigation with both worlds.

The instrument panel also provides vital feedback for the navigation of the aircraft. The compass is most important in determining heading, while the attitude indicator assists in determining the aircraft's orientation relative to a virtual world axes. The turn rate indicator provides information about the present flight profile. The VSI determines whether the aircraft is in a climb or descent. These instruments, cross-referenced with an inside-out view of the virtual world, provide necessary feedback that mimics the feedback of navigation during actual flight. However, since the ChrAVE system is a motionless platform there is a mismatch between visual perception and both vestibular and proprioceptive percepts.

This type of conflicting information is not new to the subject pool. Quite often throughout ones aviation career a pilot is placed in a position where their visual perceptions conflict with their vestibular and proprioceptive percepts. This can occur when flying either full-motion or motionless simulators, or during actual instrument flight rule (IFR) flight. In the simulator examples there is an inherent mismatch between the motion one expects, feels, and sees both in their view of the world and in their instruments. This occurs more during simulated day visual flight rule (VFR) conditions because visible reference points underscore the mismatch between views of the world and the motion administered to the user.

Conversely, when simulating day or night IFR condition, the outside world is featureless; the aircraft

pitches and rolls without noticeable change to a cloud or dark obscured view of the world. In fact, focusing on overcoming the effects of such conflicting information makes one trust in and rely on their instruments more effectively; seasoned pilots have been trained to trust their instruments over their seat of the pants feeling.

Fidelity in this research is emphasized in some areas while all but ignored others. The mock cockpit, for instance, provides a metaphor for normal cockpit interaction, but has little similarly to any actual aircraft. Yet in all circumstances fidelity adheres to this definition: the degree to which a system accurately reproduces the sensory experience of its real world counterpart, often with minimal intended distortion. This includes fidelity with regard to visual, auditory, olfactory, gustatory, tactile, vestibular, haptic, proprioceptive, etc. percepts.

It may be said that a system's collective fidelity <u>is</u> the system's interface. The interface and the feedback provided produce the system's collective sensory perception in the user's mind. Large sensory experience distortions reduce immersion, presence and may infringe on the intuitive nature of the system's input device. For example, flying with a mouse vice collective and cyclic places an unnatural burden on the user to 'learn' the system. In some instances, this can be considered negative training. A system that provides a sound sensory perception without noted distortions is assumed to place the user's mind in a realistic setting, replete with

stress, competing interests, and myriad subtasks often lost in lower fidelity systems.

G. POTENTIAL OPERATING MODES

There are numerous modes of operation the ChrAVE system can be used for, each of which may spawn its own research questions and techniques for understanding psychology and the potential of training via an embedded trainer.

In an instructor-student mode, navigational and cockpit management techniques can be monitored and coached with the undivided attention of the instructor.

As a route rehearsal tool, a route of flight can be planed and practiced, thereby providing the navigator with an acquired spatial knowledge of that area of flight without ever having actually flown there.

In a limited air-reconnaissance role the user, possibly ground combat personnel, can use it to investigate the lay of the land, key points of terrain, possible avenues of approach or departure, and lines of sight or obscuration levied by the terrain.

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IV. IMPLEMENTATION

A. HARDWARE AND PHYSICAL SETUP

The current ChrAVE system was developed as a practical intermediary step in establishing the viability and usability of embedded trainers. The ChrAVE acts as a laboratory from which to launch research into the psychology and the potential of training certain tasks via trainers/simulators. The ChrAVE primitively mocks the right half of a side-by-side dual piloted helicopter. It is meant to be rather generic to all helicopter communities.

1. Platform

The platform is comprised of a deck, pilot seat, flight controls, and some surrounding structures that emulate the walls, windscreens, and overhead of the cockpit (figure 19).

a. Seat & Flight Controls alignment

The current implementation used a Flight Link Inc. seat and basic helicopter flight controls. These controls mimic standard multi-axes game port input devices to PCs. Two axes (pitch & roll) are dedicated to the cyclic, one (thrust) to the collective, and one (yaw) to the rudder pedals. Additionally, there is a button on the collective that can be given specific assignments. The flight controls were not used by the navigating pilot during the experiment. They only provided aesthetically realistic obstacles to the task of cockpit management for the navigating pilot.

Figure 19. The ChrAVE Platform.

Figure 20. From (Flight Link Inc., 2001) Rotary Wing Hardware.

b. Cockpit Wall, Roof, and Windshield Panes

The semi-surrounding walls, roof and windscreen panes used in this implementation provided immersive visual aesthetics. These too, were designed to be realistic obstacles. These structures impede line of sight and force head movement during the task of navigation. Additionally, the deck was specifically designed and built to allow sight through a mock chin bubble. A chin bubble is a windscreen that provides sight down from the aircraft.

c. Instrument Panel

The instrument panel presentation is run on an SGI LCD monitor. Packets are sent to the instrument panel computer from the VE computer. Each packet includes the necessary information to drive each of the instruments. OpenGL and Visual Studio 6.0 are used to create network connectivity and run the graphics engine. The LCD screen provides for flicker-free viewing with the camera. A conventional cathode ray tube (CRT) monitor would have to either be equipped with a sync gen or boost the refresh rate

Figure 21. ChrAVE Instrument Panel (SGL LCD monitor).

2. Headgear

a. Head Mounted Display

The Head Mounted Display (HMD) selected maintains a high standard in performance among professional HMDs, even though its active matrix Liquid Crystal Displays (LCD) have a Video Graphics Array (VGA) pixel resolution of ((640x3)x480). Considering cost versus performance, HMDs of higher resolution were far too costly for this research. The V8 provides a CRT quality image. The V8 allows for interpupillary adjustments as well as eye relief

adjustments. The V8's earphones were not used during this research therefore they were rotated away from the ears above the headband. Audio was provided by a surround sound speaker system detailed later. See specification sheet A in Appendix A.

Figure 22. From (Virtual Research, 2000) V8 HMD.

Inputs and outputs for audio, video, and power are handled through an external control box. Red Light Emitting Diodes (LED) indicate 'Power On' and 'Stereo' modes. Standard 15 pin VGA type connectors accept VGA (640 x 480 60Hz) inputs, readily available on today's graphics engines and workstations.

b. Camera

The camera used in this implementation was an Auto Gain Control (AGC) and Electronic Light Control (ELC) Panasonic with three Charged Couple Devices (CCD), one each for red, green, and blue. See specification sheet B in Appendix A.

Figure 23. From (Matsushita Electric Corporation of America, 2002) Panasonic 3CCD Color Camera Head (GP-US532H) and CCU (GP-US522CU).

c. Lens

The camera lens used was a fixed focal length (4mm) lens. It has two adjustment rings. One is for focus and the other is for aperture f/stop settings. Changing the aperture to a lower f/stop # allows more light to reach the camera sensors but it reduces the depth of field. See specification sheet C in Appendix A.

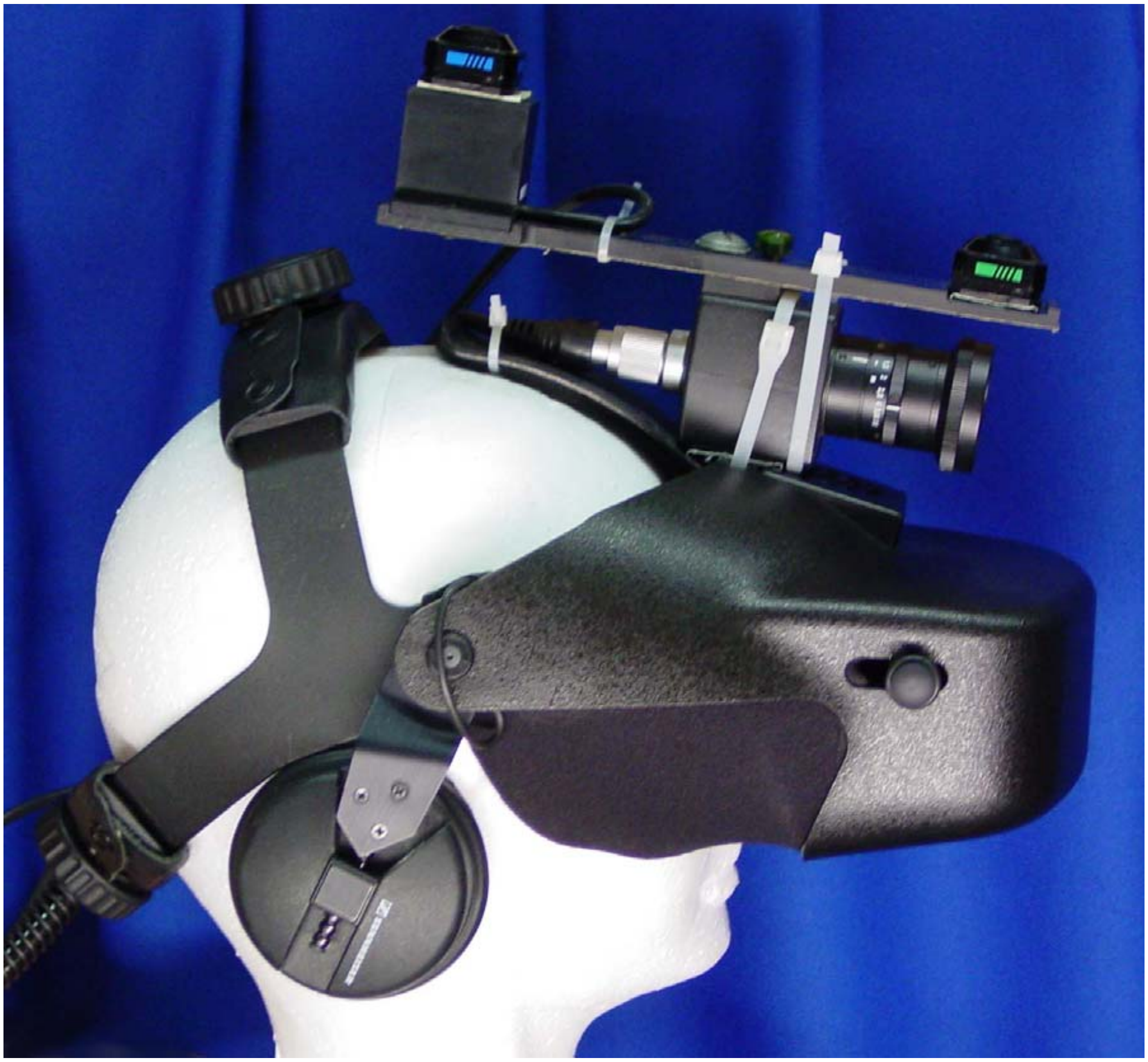

Figure 24. Photo of ChrAVE headgear.

d. Motion Tracker

The IS-600 Mark 2 was used in this implementation. It is a hybrid motion tracker that utilizes inertial and ultrasonic sensing technologies to provide 6-DOF. The Mark 2 provides multimode communication redundancy for the inertial and ultrasonic hybrid components. The inertial system is comprised of an InertiaCube™ that is strapped to the user’s headgear and tethered by wire from to the control unit. It is nearly

immune from environmental interference. The ultrasonic system is comprised of SoniDiscs™ place adjacent to the InertiaCube™ on the user's headgear and an X-bar installed overhead. The SoniDiscs™ chip an ultrasonic burst when they sense an infrared flash from the X-bar. The X-bar is equipped with microphones on each of the four pods. When the X-bar hears the ultrasonic chirp on the four pods the location of the SoniDisc™ is calculated by the control unit. The SoniDiscs™ are more susceptible to interference. They require line of sight communication and normal indoor environmental light intensities do to the infrared portion of the system. See specification sheet D in Appendix A.

Figure 25. IS-600 Mark 2 X-bar suspended from ceiling.

3. Chromakey Bluescreen Matting

A backdrop made of standard entertainment industry chromakey blue cloth panels was constructed in such a fashion so as to surround the mock cockpit from the eleven o’clock to the four o’clock. Where necessary, chromakey blue tape was used to hide seems.

Figure 26. From (Mole-Richardson Co. Inc., 2001) 2-inch wide chromakey blue tape.

4. Lighting

Lighting is by far the most temperamental component to implementing chromakey technology. The chromakey mixer must perceive the chromakey blue backdrop (called the matting) without noise such as being unevenly lit and having shadows. A number of fluorescent lamps were placed about the mock cockpit in such a manner so as to light the matting while not impeding the navigator’s view of the matting. An additional hurdle was ensuring that the lamps

did not directly shine into the camera lens or the sonic disks. Although the sonic disks are alerted to infra light, the intensity of the fluorescent lamps can create sufficient noise to disrupt proper motion tracking.

This implementation employed four fixtures that were four feet in length and four fixtures that were two feet in length.

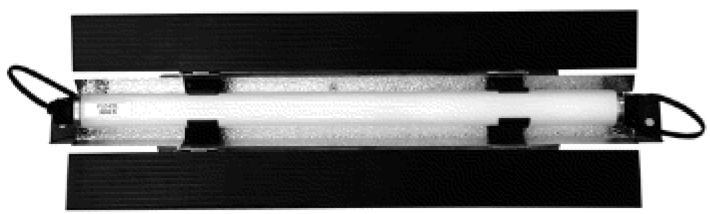

Figure 27. From (Flo Co, Inc., 2001) Solo Fluorescent™ Lamp.

Each fixture had high output flicker-free ballast that operated on 120 VAC/60Hz. Each fixture also included a specular reflector, and two lamp barn doors.

5. Signal Converters and Mixer

A number of signal converters were used in the system. The system demands that signal quality and integrity be maintained throughout the video pipeline. The Ultimatte™ 400 Deluxe chromakey mixer was the cornerstone used in this implementation and required a CCIR-601 signal as input. Therefore, both the foreground (FG) signal (an RGB signal from the camera) and the background (BG) signal (a VGA signal from the CPU) had to be converted. Furthermore, once the FG and BG signals were mixed, the CCIR-610 output

signal had to be converted back to a VGA (640X480) signal for the HMD.

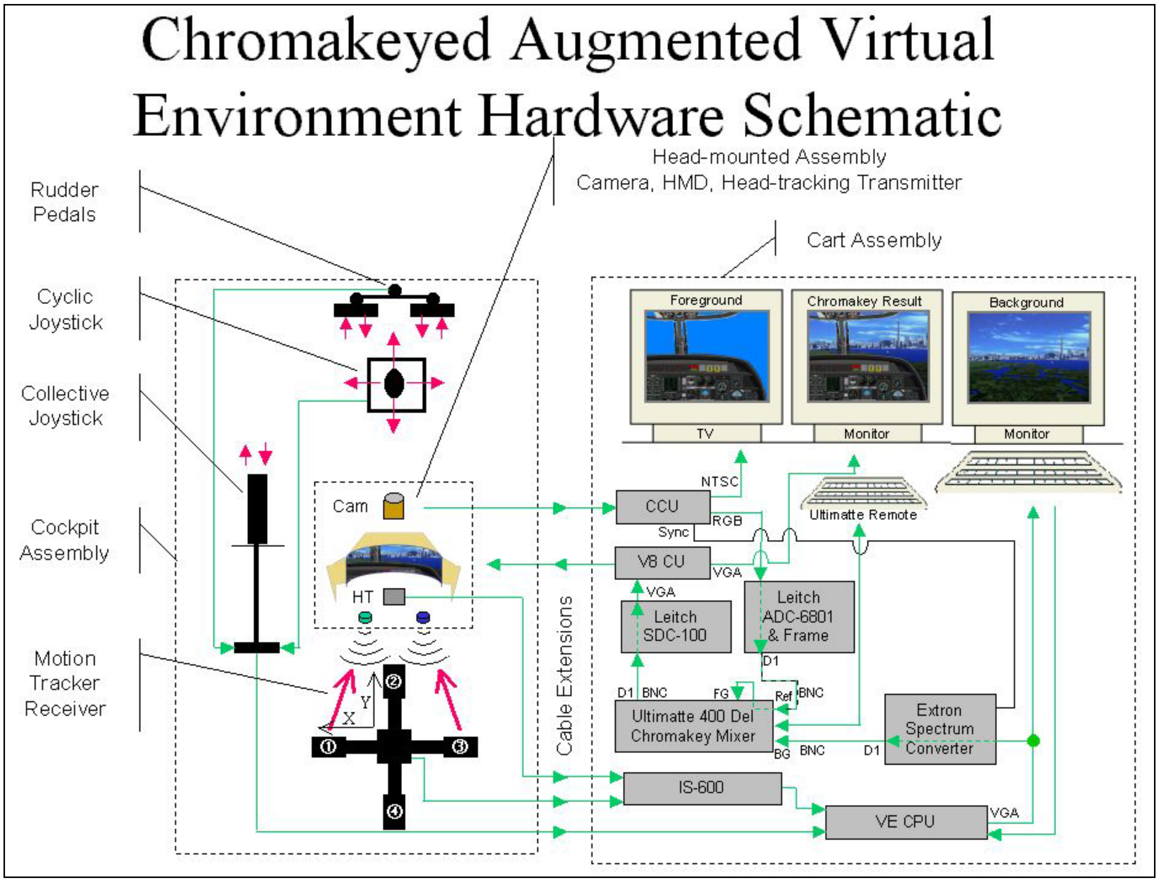

Figure 28. Schematic of the ChrAVE System.

a. Virtual Environment VGA to Digital 601 Signal Converter

In order to accommodate the Ultimatte™ 400 Deluxe chromakey mixer's input signal demands, an Extron™ Electronics VSC 200D video scan converter was used to convert the virtual environment CPU's 15-pin VGA video signal into a digital CCIR-601 signal. See specification sheet E in Appendix A.

b. Camera RGB to Digital 601 Signal Converter

The Panasonic™ GP-US542 3-CCD High Performance Color Camera produces an RGB signal that must be converted to a digital CCIR-601 signal for input to the Ultimatte™ 400 Deluxe chromakey mixer. The Leitch™ ADC-6801 signal converter serves this purpose. See specification sheet F in Appendix A.

c. Chromakey Mixer

The Ultimatte™ 400 Deluxe chromakey mixer takes two digital CCIR-601 signals (a camera feed and a CPU VE feed), merges them into a single video image using chromakey technology, and outputs the resulting digital CCIR-601 signal. See specification sheet G in Appendix A.

d. Digital 601 to VGA Signal Converter

A Leitch™ SDC-100 serial digital to VGA converter was employed to return the digital CCIR-601 signal from the Ultimatte chromakey mixer to a useable signal for the V-8 HMD (VGA 640X480). See specification sheet F in Appendix A.

Figure 29. Photo of ChrAVE cart.

B. SOFTWARE

The software selected and used on the VE CPU in this implementation cornerstoned MultiGen-Paradigm's Vega virtual environment software. Vega features a fairly intuitive API application called Lynx that allows connectivity between objects (observers, models, terrain, effects, etc.). The VE CPU broadcast packets to both the instrument panel CPU and the top-down view CPU. All three computers employed OpenGL. Microsoft Visual C++® 6.0 was also installed on all three CPUs. It served as the platform upon which OpenGL and Vega ran.

Models and terrain were created using MultiGen-Paradigm's Creator software. This software allows for importation or creation of geometric models as well as textures for mapping onto the models.

V. METHODS

A. EXPERIMENT SETUP

1. Subject Pool

This experiment used fifteen designated military helicopter pilots. All subjects were male students of the Naval Postgraduate School (in a non-flying status) and were either U.S. Marine Corps or U.S. Navy pilots. Since all subjects were designated pilots they meet the expert criteria with regard to the knowledge about, and skills involved in, the activities of a multitasked cockpit environment. Dynamic prioritization of the tasks at hand is a critical quality required for all helicopter flight regimes.

2. Treatment

Each subject’s participation involved an entrance questionnaire, followed by map preparation for the route of flight, a battery of physiology tests prior to flight, the low-level navigation flight, a battery of physiology tests following the flight, and an exit questionnaire. Lastly, each subject was asked to evaluate the performances of their peers.

a. Entrance Questionnaire

The questionnaire, which can be found in Appendix B, briefly asks about medical history, flight experience, and parameters for conducting acceptable low-level helicopter navigation. A series of slides were shown to each subject depicting an intended route of flight with checkpoints and a fictitiously flown flight path. Additionally, fictitious estimations of where checkpoints

were located were also depicted. Subjects were asked to evaluate each slide as either acceptable (pass) or not acceptable (fail). This provided a baseline estimation of acceptable performances across all the helicopter communities represented. The slides each subject was to evaluate can be found in Appendix B. They were randomly lettered and presented to the subject in no specific order.

b. Tasks

The tasks each subject was to perform can be found in Appendix B (questionnaire pages 4-5). Each task was included in order to provide the subject with a realistic navigational workload.

Figure 30. Preparing a map for an intended route of flight.

Since we cannot compare ChrAVE results to results of actual flight due to the unavailability of real aviation resources, the opinions of actual pilots tasked with realistic workloads appears beneficial in partially determining whether a system such as the ChrAVE is viable as a laboratory for continued training in virtual environment experiments.

The subjects were provided necessary resources (Appendix B, (questionnaire page 4)) including scissors and tape to completely prepare their map for the intended route of flight (figure 30). The subjects were additionally, provided flight parameters (Appendix B, (questionnaire page 4)) in order to correctly prepare their maps with regard to time checks and to establish a mindset for the tempo of the flight. There was no time limit in map preparation or map study. Map preparation and map reconnaissance are initial steps use with 2D familiarity of an area.

c. Physiology Tests

A battery of physiology tests were administered four times throughout the experiment.

1) The unhooded baseline battery was conducted just prior to the subject donning the ChrAVE headgear. It provided a baseline of the subjects at rest from which to measure any future degradation.

2) The initial HMD exposure battery was conducted immediately following the donning of the headgear.

3) The extended HMD exposure battery was conducted following the flight portion of the experiment.

4) The unhooded recovery battery was conducted immediately following the removal of the headgear.

In each battery there were four tests:

1) Visual acuity test was intended to show any apparent degradation in the ability to read writing on the map while hooded. A simplistic eye chart (figure 31) created in Microsoft Word consisting of lines of random letters. The lines of letters had point sizes ranging from 50 points to 8 points. All letters were in the courier font. Subjects were handed the chart and asked to read the smallest line possible. Subjects were allowed to present the chart as close to their eyes or camera as needed.

2) Color identification test was intended to show any apparent degradation in the ability to correctly perceive colors on the map while hooded. Once again, the eye chart in figure 31 was utilized. Six lines (blue, red, green, orange, purple, and black) with a width of three points were depicted. Subjects were handed the chart and asked to state the perceived color of each line. Subjects were allowed to present the chart as close to their eyes or camera as needed.

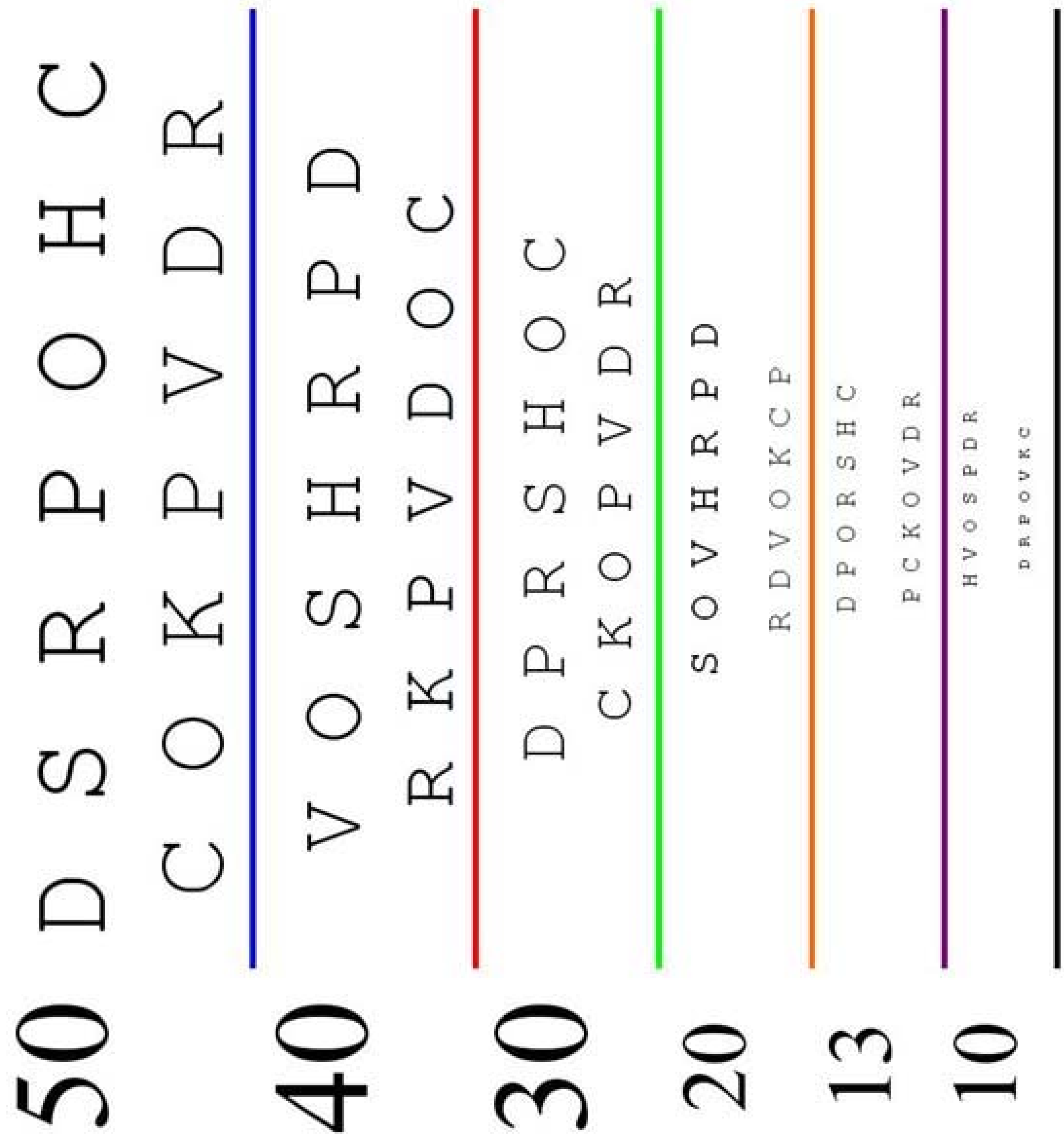

Figure 31. Visual Acuity and Color Identification Eye Chart (Actual size not depicted.)

	Blue	Red	Green	Orange	Purple	Black
R	0	255	0	255	128	0
G	0	0	255	102	0	0
B	255	0	0	0	128	0

Table 1. R-G-B values use to define the colors in the color identification test.

3) Dvorine psudo-isochromatic plates were intended to determine the extent to which the ChrAVE introduces color blindness to subjects wearing the HMD. Subjects were handed the chart and asked to state the perceived number on each plate. Subjects were allowed to present the plates as close to their eyes or camera as needed, however the plates had to remain at a right angle while being viewed. Additionally, subjects were not allowed to trace the number on the plate. All other established administration procedures were enforced. Delays of more than five seconds resulted in an identification failure for that plate.

The *Dvorine Color Vision Test* consists of a bound set of color plates. These plates feature a number or design made up of colored dots against a background of contrasting dots. The figures are easily identified by persons with normal vision, but not by those with color blindness.

4) Hand-eye coordination test was intended to show any apparent degradation in the ability to interact physically with the real world. The test entailed the subject sitting in a chair three feet from the proctor who was also sitting in a chair. The proctor would toss a ball to the subject ten times. The subject was supposed to catch the ball using one or two hands. A legal toss consisted of an apex never higher than the subjects head and never lower than the subjects shoulders. Each toss was graded as a catch (no discernable fumbling), a fumble (fumbling, but not dropped), and a drop.

Figure 32. Hand-eye coordination catch test, both unhooded and hooded with the ChrAVE head assembly.

d. Virtual Navigation

A navigational warm-up lasting approximately three minutes was conducted. During this period, subjects were exposed to turns to the left and right using both standard and half standard rates. The proctor verbally made note of the length of time it took to roll into and out of these turns. Additionally subjects were instructed to provide the necessary verbal commands to fly perpendicular to a road and then turn left so as to align the aircrafts flight along the road. This drill displayed two things to the subjects, 1) that the turning radius of the ChrAVE was rather wide and 2) that turns to the left limit the navigator's view.

Following the warm-up, the subject was suspended in space at the course entry point and allowed to establish their orientation using the compass, map, and the available

views. When the subject was ready, the sound file was cued and the aircraft began to fly.

Subjects had to listen for radio calls; calls correctly identified and responded to were noted by the proctor. Periodically demands for the subjects to plot their position and orientation were issued; these calls came about every two minutes. Additionally, subjects had to provide navigational instructions to the proctor.

This flight lasted 30 minutes. In that time, the subject was supposed to negotiate as much of the course as possible. The proctor only provided guidance by form of cardinal heading, if the subject was hopelessly lost or about to fly out of view the top-down viewing monitor or off their paper map.

e. Exit Questionnaire

The exit portion of the questionnaire (Appendix B, (questionnaire pages 9-11)) was presented to the subjects following the unhooded recovery battery of physiology tests.

f. Debrief

After completion of the questionnaire, the subjects were invited to view their performance on the top-down viewing monitor. The proctor would point out observations and key points during the flight. The flight path and position plots of each subject’s performance is depicted in Appendix C.

g. Subject Peer Evaluations

Following the subject pools navigational efforts, each member of the subject pool was presented with the top-

down vies of the flight path and position plots of the entire subject pool. They were asked to evaluate each ChrAVE performance on the following three criteria:

- The subject’s ability to maintain a flight path in acceptable proximity to the intended path.
    - Considering the Fort Irwin terrain, evaluate the subject’s ability to fly the intended route and hit the checkpoints. The intended route and checkpoints are green while the subject’s flight path is red or yellow.
    - Rate the performance using a 1 to 7 scale, '1' indicating highly acceptable while '7' indicates not acceptable.
    - This criterion is independent of the following criteria, meaning the proximity to the intended flight path is to be evaluated independently of whether or not they knew where they were.
- The subject’s ability to correctly estimate their location.
    - Considering the Fort Irwin terrain, evaluate the subject’s ability to accurately locate and plot his position (including heading) on demand. Aircraft icons of matching color help to pair a subject’s estimated and actual locations. Note the icon outline color. Where necessary, white lines help group the pairs.
    - Rate the performance using a 1 to 7 scale, '1' indicating highly acceptable while '7' indicates not acceptable.
    - This criterion is independent of the preceding criteria, meaning the accuracy of the position estimation is to be evaluated independently of whether or not they were on the intended route.
- The overall performance.
    - Rate the overall performance as acceptable or not acceptable (‘A’ or ‘N’)

The results of these peer evaluations are listed in Appendix E.

B. KNOWN ARTIFICIALITIES

The ChrAVE system incorporated many known artificialities; some were desired, some were not.

1. Physical Perceptions.

a. Optical Artificialities

Real world color is presented to the subject with minor deviations. These color deviations occur along the foreground or real world pipeline. This pipeline consists of the camera, RGB to digital 601 signal converter, the chromakey mixer, the digital 601 to VGA signal converter, and the HMD. Most likely the HMD has the greatest effect on perceived color deviations to the user. The mixed signal going in to the HMD is looped through to a monitor for the proctor’s use. This monitor displays less color deviation than the HMD proving that the pipeline prior to the HMD has less of a contribution to color deviation.

The camera is equipped with an automatic gain which adjusts the brightness level of the camera’s signal. The HMD is most effected by the automatic gain adjustments. The user can perceive alternating periods of real world brightness and darkness with rapid head movements that go from repeated head down to head up.

The lenses of the HMD introduce astigmatism to the user. This is most noticeable with large head movements while viewing an un-augmented real world view;

the astigmatism is almost undetectable while viewing mixed real world and VE signals.

The camera lens had a fixed focus range that allowed objects within arms reach to be in focus while more distant objects were out of focus. For the most part all items that had to be in camera focus were within arm’s reach. A blurred blue screen actually aided in smoothing any shadows or wrinkles captured the keyed matt.

The static FOV of the HMD was 60° on the diagonal. Such a small FOV did not allow for a periphery view being presented to the user. Users commonly compensated for this narrow FOV with extra head movements.

The aggregate VE FOV was limited to the coverage of the blue screen. Its coverage was approximated the user’s eleven o’clock to the four o’clock. The user is more impaired while looking across the cockpit than in the real world.

b. Auditory Artificialities

During actual flight a pilot will hear varying sounds as the rotors beat the air during climbs, descents, and turns. Additionally, a pilot would hear an electrical culmination of engines, radio static, and other electrical equipment fed to him over the internal communications system (ICS). These also vary during different flight maneuvers and equipment usages.

During the virtual flight phase of the experiment subjects were exposed to a 30-minute helicopter recording that a pilot might hear. Rotor sounds did not vary with climbs or descents, nor did the electrical ICS sounds.

Random radio calls were included. Additionally, radio calls to the subject’s aircraft and about the subject’s aircraft were included. Calls to the aircraft were expected to be acknowledged. Lastly, approximately every two minutes the subject would here a beep followed by the words “plot your position now”.

(1) Radios and Volume control

The recording was comprised of engine whine, rotor thumping, and radio calls. It was not possible for the subjects to increase the volume of the radios, like they might in actual flight, without increase all the helicopter sounds as well.

Radio calls may have been scratchier than in actual flight.

(2) Helicopter Noise (Bass)

Headphones were not use. The recording was presented to the subject via five speakers, two in the front, two in the rear, and a sub-woofer placed behind the seat of the subject. Bass of the recording was presented to the subject in a louder then normal representation to provide the feel of aircraft vibration.

c. Vestibular Artificialities

The ChrAVE does not incorporate a motion platform. Therefore, there will be obvious intersensory conflict between physically sensed motion and visually perceived motion. However, since the ChrAVE is intended to be a deployable training system, it is important to

recognize vestibular differences between the ChrAVE and actual flight with both a land based and sea based ChrAVE.

(1) Non-motion (land/docked)

The intersensory conflict of a land based ChrAVE resides between visually perceived motion and the absence of any physical motion.

(2) Unsynchronized motion (at sea)

The intersensory conflict of a seabourne ChrAVE resides between visually perceived motion and the sensed physical motion dictated by the current sea state. Although a seabourne ChrAVE was not used in this experiment this statement is made with relative certainty.

2. Ergonomic Artificialities

a. Generic Airframe

The generic cockpit was metaphoric in nature to any actual helicopter, and did not reproduce any ergonomic features of any aircraft with high fidelity.

b. Instrument Panel

A generic navigational instrument panel was established which incorporated necessary instruments of low-level navigation (altimeter, magnetic compass, attitude indicator, turn indicator, vertical speed indicator, airspeed indicator).

c. Size of Instruments

The instruments were rendered larger than normal to overcome viewing difficulties inherent with the selected

camera lens. Also the blue sky of the attitude indicator was replaced with orange to avoid chromakey blue matching.

d. NVG / HMD Difference

The HMD was reported by many subjects to be similar to NVGs. However the HMD has a baffle that does not allow site outside of the HMD, whereas NVG allow below, left and right of the device. Peripheral site is not available in the ChrAVE with the HMD's current configuration.

e. Helmet / HMD, Tracker, Camera

The weight of the camera, HMD, and worn tracker components was comparable to that of actual flight however the balance was not. The ChrAVE's head gear weight resided almost entirely in the front, thereby applying bothersome pressure to the bridge of the nose and fatigue to the back of the neck..

f. Clock and its Familiarity

The clock provided to the subjects was not a typical timing device purchased by aviators. Nor was the clock similar to the standard seven-day clock found in naval aircraft. The clock counted down to zero as opposed to counting up to a specific time of a given leg. This complicated quickly ascertaining the aircraft's progress of a given leg. Seeing say, 0:45 on a countdown of a 60 second leg is different from seeing the normal display of 0:15 seconds of elapsed time the subjects were use to. This was not intended; it was an oversight.

3. Flight Profile Artificialities

The subject pool did not have a single aircraft in common. The ChrAVE attempted to accommodate all helicopter pilots with a single generic set of flight characteristics.

a. Airspeed

Airspeed was pegged at 90 knots and did not vary in any flight profile.

b. Windless Day

All flight was conducted in a windless environment. Therefore airspeed matched groundspeed in all directions. This simplified and isolated performance with regard to timing distances while navigating.

c. Constant Zero Pitch

The ChrAVE maintained it's nose on the horizon in all flight profiles. This minimized the possibility of disorientation due to varying pitch.

d. Rotor Head Chops Off Special Effects

An anti-aliasing shortcoming that could not be overcome resulted in the virtual spinning rotor head, which was visible to the users, chopping off any environmental special effects. For instance, a plume of smoke that rose up from the ground should have been seen as it extended beyond the spinning rotor blades. It did not.

e. Rate of Turn

Again, in order to avoid the possibility of disorientation due to a tight rate of turn the ChrAVE made turns that were much wider that the subjects were use to. In fact, rate of turn may have presented the greatest adjustment to normal flight for the subjects.

f. Limited to 1/2 SRT or Full SRT

The ChrAVE either flew wings level, in a half standard rate turn (3° of heading change per second with 22° of angle of bank, or a full standard rate turn (6° of heading change per second with 45° of angle of bank. Transition between these profiles was automated with an algorithm that mimicked normal acceleration into and out of all turns in the roll axis. Doing so provided a smooth realistic platform for navigation while minimizing the user’s disorientation and disruption of immersion.

4. Tasks Artificialities

a. Map Prep

A few map preparation artificialities were introduced to the subjects but were probably negligible. The subject pool was instruction to prepare their route of flight as though it was a day or night flight. In night flight map preparation bolder route depictions are used for easy visibility in a dark cockpit.

Additionally, the subject pool was not afforded either a flight calculator commonly referred to as a wiz wheel or a plotting stencil. Seasoned pilots could easily overcome such hurdles. Frankly, they were not included because it was felt that although these tools are available in fleet map preparation they are not often used and by including them might draw attention to their inclusion and distract the subjects from preparing as they normally would. A protractor was included.

b. Navigation

During the task of navigation military helicopter pilots use the terrain to mask their position and provide cover. Such flight would have them divert from strictly adhering to a route of flight. During this experiment the subject pool had to overcoming the instinct of flying in tactical manner. This proved uncomfortable to many of the subjects; many subjects made verbal comments on this point. It should be noted that the ability to make dynamic tactical modifications to a given route of flight invokes and added dimension of complexity to the task of navigation. This study wanted to isolate the task of navigation itself in the ChrAVE.

Additionally, the subjects plotting their position about every two minutes was not only excessive but was also used as a timing device standard by some. Plotting was necessary to compile data as to the subject’s awareness to where they were. Some abandoned their own timing and relied on the periodic announcements to estimate their timing.

c. Division of Duties

Normally there are certain divisions of duties amongst the pilots. In order to establish the situational awareness of each subject they were instructed to verbally report any air traffic and ground activity they may encounter. This is fairly normal, but knowing that the PAC would not be assisting them may have created undo concerns. Furthermore, assistance from the PAC in terrain recognition meant that the navigator would have to work harder to personally compare the outside view to the map. Normally

the pilot at the controls would assist in identifying terrain features in front or on the PAC’s side of the aircraft. The navigator describes what the flying pilot should see; the flying pilot confirms the description or states what he sees.

d. Radio Calls

The task of monitoring the radios varies from helicopter community to community, if not from aircrew to aircrew. Sometimes the PAC handles the calls, sometimes it’s the navigator. A novice navigator that is able to handle radio calls in addition to the other navigational duties is the exception. Most novice navigators are usually task limited due to the demands of navigation. In this experiment, artificiality was introduced with regard to responding to the radios. The subject was told their call-sign, “Ugly one-two”. Instead of directly responding to calls for them, they were instructed to respond by saying their “Ugly one-two” as a form of acknowledgement.

C. DATA COLLECTION

Data collection came in the form of

1. Questionnaire & Evaluation Forms (to include physiology test results)

A survey, in the form of a questionnaire (Appendix B), was conducted to gather data and information on acceptable low-level navigation criteria and prioritized indicators effective navigational task performance. Paragraph A.2.c of the Methods section has more detailed explanations of each of the tests.

Additionally, physiology tests were conducted on each subject with the headgear off and on.

a. Visual Acuity

This test was intended to show the degradation in the ability to read writing on the map while hooded.

b. Color Identification

This test was intended to show the degradation in the ability to correctly perceive colors on the map while hooded.

c. Dvorine Psudo-isochromatic Plates

This test was intended to determine the extent to which the ChrAVE introduces color blindness to subjects wearing the HMD.

d. Hand-eye Coordination Test

This test was intended to show the degradation in the ability to interact physically with the real world while hooded.

Refer to figure 36 to view the results of the physiology tests.

2. Recorded Virtual Flight Data

The ChrAVE system generated packets containing position and orientation data that was written to a file. The data was collected about once every second. The data was play through a

3. Maps of the Subjects in the Pool

The subject pools maps were view following the virtual low-level navigation flight. The maps contained the periodic plots (position and heading) of the subject as well as an indicator of skill used in preparing their map.

4. Debrief Comments of Subjects in the Pool

Following low-level navigation flight members of the subject pool were debriefed. Many uttered comments that were positive both critical. Common comments are noted in sections VI-VIII.

5. Subjects' Peer Evaluations

In the initial questionnaire questions 20 through 25 have the subject pool determine acceptable criteria limitations for navigational flight. Once each member of the subject pool flew the virtual low-level navigation route the subject pool was tasked with reviewing the performances of each member of the pool and pass judgment as to which performances were acceptable and which were not. Appendix D contains the peer evaluations from every member of the subject pool upon every other member. Paragraph A.2.g of the Methods section has more detailed explanations of each portion of the peer evaluations and the criteria used.

VI. RESULTS

Figures 33 and 34 exhibit differences in the utilization of preparation tools when land based and sea based. Most notable is that satellite photo usage while at sea gained eight percentage points over land based usage while map study had virtually the opposite effect. This may be partly due to the availability of satellite imagery while at sea.

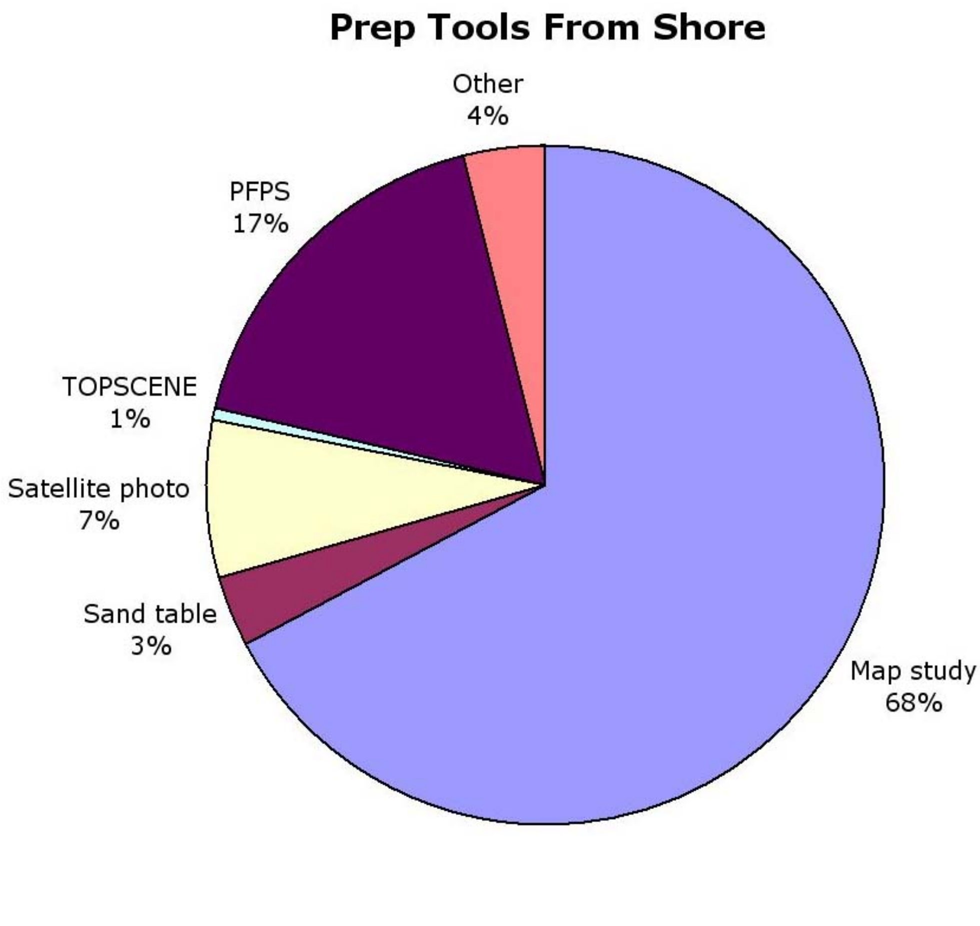

Figure 33. Preparation tools for low-level terrain navigation flights when land based.

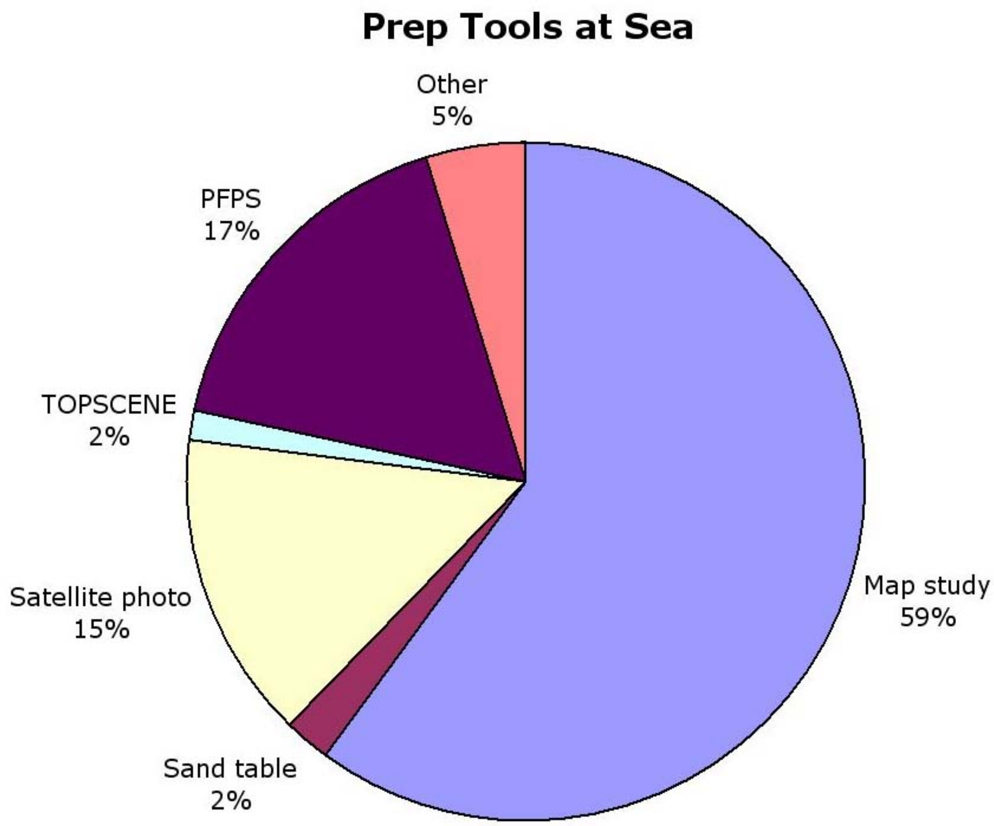

Figure 34. Preparation tools for low-level terrain navigation flights when land based.

Attempting to establish the criteria for determining effective navigation is difficult. Complicating the issue are the numerous circumstances that can occur at any point throughout a flight. Two navigational fundamentals are 1) knowing your present location and 2) identifying the path and checkpoints along intended route. These are independent of each other, for example, a navigator may know his present location by terrain association but not be able to identify points along the intended route. Conversely, the navigator may be able to identify points along the intended route but estimate his location poorly.

Other possibilities include a navigator being on course but not knowing his location or being unable to identify any points along the intended route. This last example demonstrates the difficulty in empirically evaluating the performance of a navigator; collecting flight data does not indicate the navigator’s state of mind and situational awareness.

The evaluation slides presented to each subject depicted the flight path of a fictitious navigator (empirical type data) and the navigator’s estimation of where the checkpoints were. These estimations give insight to the navigator’s ability to identify points along the intended route. These estimations are not empirically collectible in real flight. During actual low-level navigation training, the student navigator indicates where checkpoints are through conversation and pointing. These are not empirically verifiable means, however, it is through these means that the navigation instructor gains insight to the student navigator’s state of mind while identifying points along the intended route.

During the navigational portion of the experiment, flight data was empirically collected and the subjects were instructed to plot their location periodically. Stress, workload, and the degradation in the ability to see and interact with the map are all factors led the subject’s to plot their positions with an unknown degree of error. When the subject was told to plot his position, the proctor recorded the aircraft’s position and heading. Once the experiment was complete the proctor created an 8-digit grid number and heading for each plot made on the map by the

subject. These too contain an unknown albeit manageable degree of error. All data was then visually rendered in a top-down view. The top-down view allows one to compare the actual position and orientation of the subject versus the subject's estimation. The differences in heading and location are then determined and constitute progression towards a useable metric for determining the subjects state of mind and situational awareness. See Appendix C for the subject pool's top-down.

The subject pool was anonymously presented the flight performances of all other subjects in the pool for evaluation. Only the top-down visual renderings were presented; they were not privilege to the empirical performance data. The peer evaluations that are tallied in table 19 (the three right most columns) were based on three basic criteria:

1. The subject's ability to maintain a flight path in acceptable proximity to the intended flight path.
2. The subject's ability to correctly estimate their location and orientation.
3. The subject's overall performance.

The first two criteria were rated using a scale from one to seven, one indicating highly acceptable and seven indicating not acceptable. The first two criteria were also independent of each other, meaning the proximity to the intended flight path was evaluated independently of whether or not the subject knew where they were and the accuracy of the position estimation was to be evaluated independently of whether or not the subjects were on the intended route. The last criteria was based on the overall

performance of the subjects and evaluated as acceptable (pass) or not acceptable (fail).

Reflecting on the subject pool’s collective response to question #22, which asked what the threshold between acceptable and substandard navigational performance was for flight over an intended checkpoint, the subject pool collectively stated that flight within 260 meters of a checkpoint was acceptable. Based on each subject’s flight data (Appendix C) the subject pool on average flew within 260 meters of a checkpoint 3.2 times out of a possible 14 (see table 19 in Appendix E, center column).

Granted, some checkpoints were harder to find than others. Additionally, the ChrAVE’s motion model artificially limited the radius of turn to help prevent disorientation among the subject’s, which meant that although subjects may have seen their next checkpoint, they may have been limited in their ability to fly over it.

Proximity to a checkpoint is but one factor in identifying effective navigation. Question #24 (below) of the questionnaire asked the subject pool to order the importance of a list of proposed navigational yardsticks. It is understood that this is not a complete list of all possible criterion that make up effective navigation. However, it does attempt to gain insight as to what is most important in order to establish metrics for evaluating navigational performances. Some of these can be empirically evaluated while others appear difficult to evaluate without disrupting navigational activity. When the subjects were told to plot their position, it was

disruptive to their other navigational tasks, albeit minimally disruptive.

Question 24 of the questionnaire asked the subjects to number the following in order of importance:

- ___ Maintaining the route of flight
- ___ Accurately knowing your present location (plotting to 8-digit grid accuracy)
- ___ Accurately hitting your checkpoints
- ___ Being off the intended route of flight and intending to intercept at the next check point
- ___ Knowing your location by reference to a dominant terrain feature (plotting to 4-digit grid accuracy)
- ___ Seeing your checkpoints, but not hitting them
- ___ Being off the intended route of flight but working towards it

The following table is the result of the above question. The subject pool collectively regarded knowing one’s location by reference to a dominant terrain feature (with the ability to plot the position to a 4-digit grid accuracy) as most important. This was followed by accurately hitting one’s checkpoints and then accurately knowing one’s position to an accuracy of eight digits. Next was maintaining the route of flight, followed by the off course possibilities.

Again, determining the extent to which a navigator knows their location and the location of the route and checkpoints is difficult to empirically ascertain.

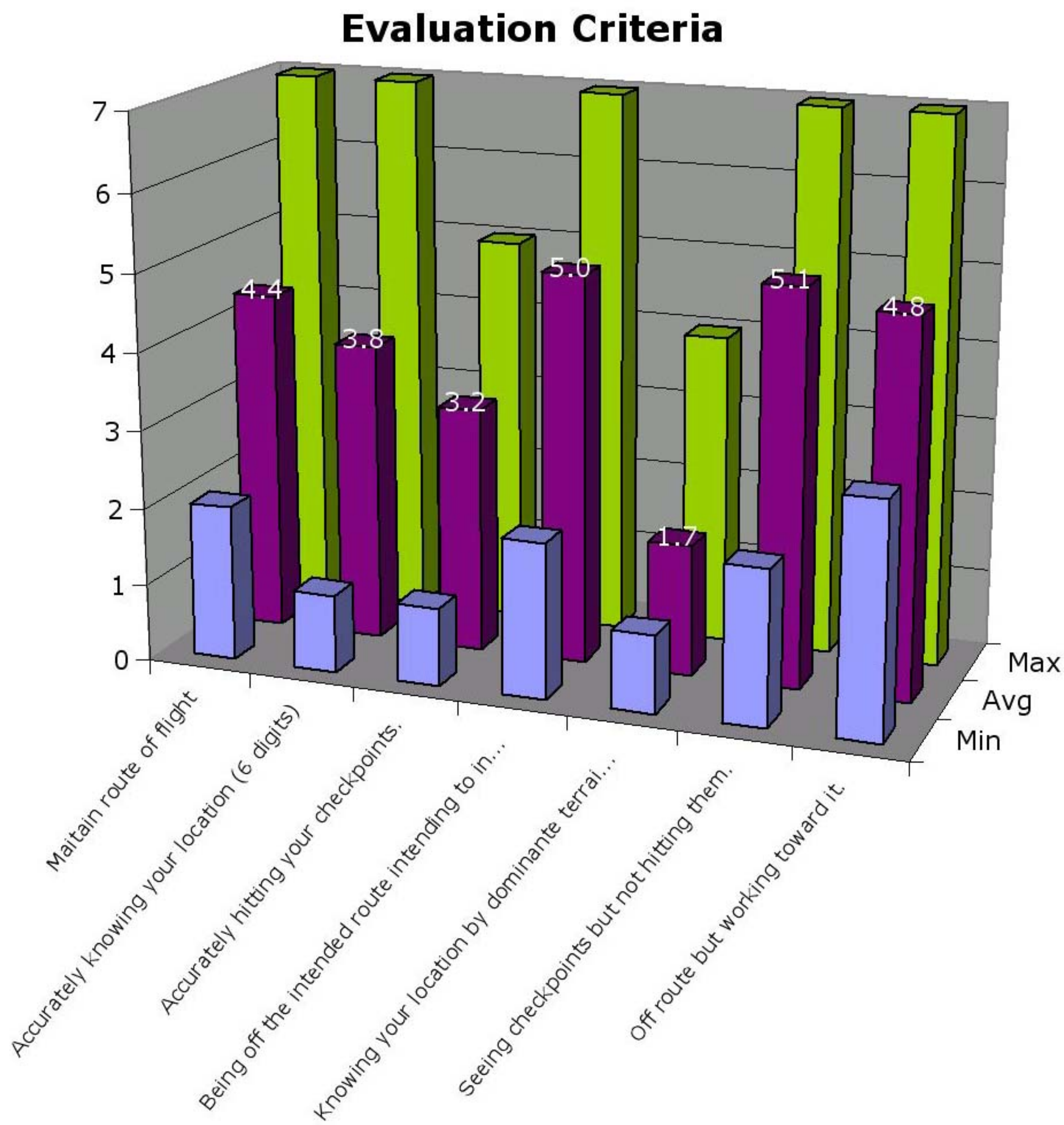

Figure 35. Low-level navigation evaluation criteria in collective order of importance as indicated by the subject pool.

The results of the physiology tests indicate that impairment of prolonged exposure to the ChrAVE lessened over time. Most notable is the improvement of hand-eye coordination of the subject pool’s initial donning of the

ChrAVE’s headgear to the completion of the flight which on average accounted for 63.47 minutes of ChrAVE exposure.

The physiology results also indicate that the camera introduced color distortions that impaired the subjects by 36.7% of the baseline battery, yet color blindness of any sort was not increased by a corresponding amount.

Lastly, the unhooded post-exposure battery nearly replicated the results of the baseline. Although subject’s appeared to show some lingering effects during the first throw of the hand-eye coordination test, rapid improvement was noted. Tosses two through ten had nearly identical catching results to the baseline.

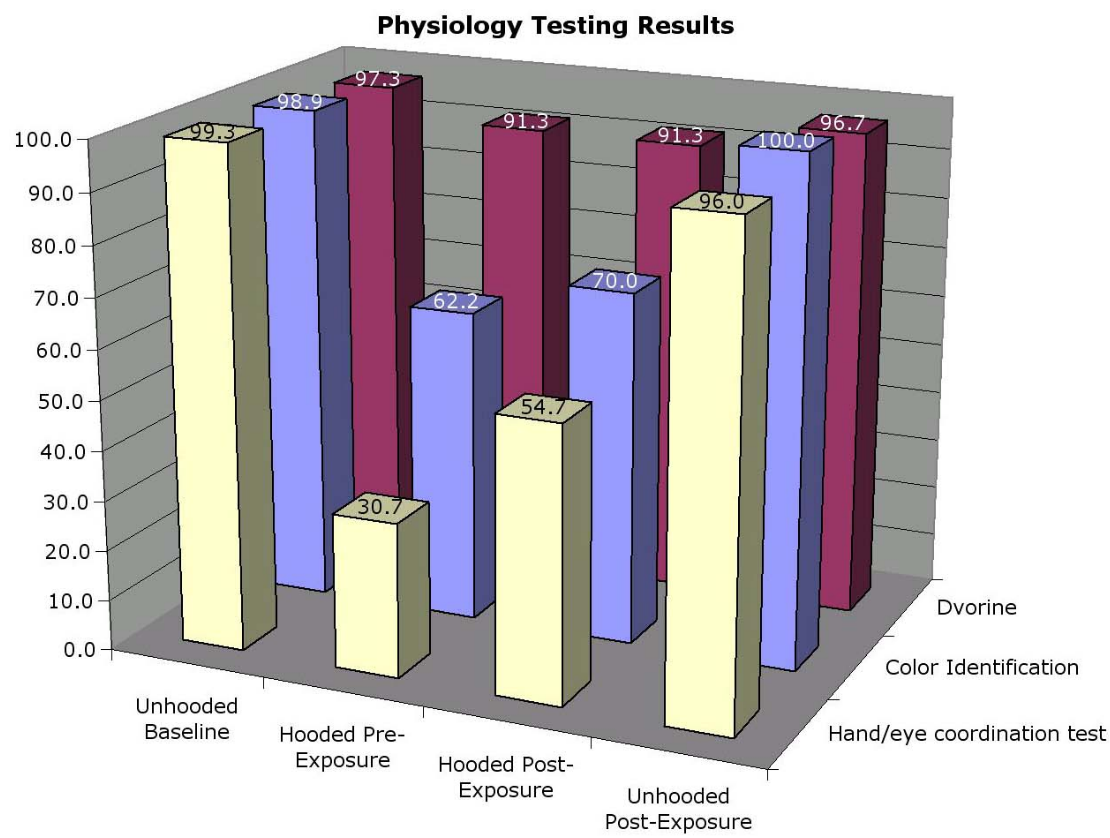

Figure 36. Physiology results indicating impairment during the course of the experiment.

Table 2 is empirical data indicating the closest proximity to each checkpoint during the negotiation of the route. On the right of the table there is a column indicating each subject's average proximity to the checkpoints. The right most column of the table tallies the number of checkpoint proximities that are within the subject pool's 260-meter threshold. Only one subject in the pool was able to maintain an average distance of less than 260 meters.

		Check Points													
		1	2	3	4	5	6	7	8	9	10	11			
	Subject	Course Entry Point	Cemetery Bend	Granite Pass	Whiskey Saddle	Romeo Hill	Hill 1161	Nelson Lake	McLean Lake Feed	Tri-valley Pass	Drinkwater Lake	Course Entry Point	Average Distance **	Proximity Rank	Number Acceptible ***
Min Distance from Flown Path to Checkpoint (Meters)	001	0.0	288.6	528.9	473.3	187.7	183.1	71.0	462.6	969.4	214.7	779.3	375	2	4
	002	0.0	265.1	511.9	71.6	122.1	1008.2	389.3	250.6	598.4	230.3	146.6	383	3	5
	003	0.0	271.0	311.2	1399.3	357.8	882.3	33.6	357.8	4,665.4	3,307.1	3220.2	1287	14	1
	004	0.0	1089.1	183.4	157.9	1,022.6	192.6	144.9	419.1	824.8	4,985.1	5059.5	1002	13	4
	005	0.0	610.0	131.6	1306.7	1,631.8	230.7	252.1	1155.8	501.3	159.1	4186.5	664	10	4
	006	0.0	418.4	36.7	395.4	462.6	941.0	5,345.5	3421.7	2,031.9	275.5	2250.5	1481	15	1
	007	0.0	421.6	504.7	3084.1	1,092.4	412.9	118.6	208.1	534.4	31.3	1723.9	712	12	3
	008	0.0	394.9	1,600.1	639.8	1,751.7	192.0	349.4	572.5	539.8	254.3	32.2	699	11	3
	009	0.0	949.2	204.9	297.5	2,119.6	167.2	211.0	397.4	733.7	251.4	539.5	592	8	4
	010	0.0	461.4	70.9	23.8	309.9	261.9	30.3	242.8	563.9	130.0	456.3	233	1	5
	011	0.0	478.9	59.7	245.0	1,464.7	211.0	209.5	674.1	1,101.9	476.1	283.1	547	5	4
	012	0.0	472.1	240.5	60.7	1,653.0	604.2	253.2	726.4	694.1	75.1	1363.4	531	4	4
	013	0.0	466.0	204.2	129.4	704.2	1598.9	639.9	670.1	334.3	1,122.6	476.7	652	9	2
	014	0.0	711.9	296.7	403.9	2,082.7	280.9	77.3	380.5	835.3	120.1	104.2	577	7	3
	015	0.0	460.0	53.2	380.0	1,218.9	362.6	693.7	726.2	755.5	538.5	1184.7	577	6	1
Average Distance-->		0.0	517.2	329.3	604.6	1,078.8	502.0	587.9	711.0	1,045.6	811.4	1,453.8	688		
Difficulty Ranking*-->		N/A	7	9	5	1	8	6	4	2	3	N/A			
Num Acceptable ***-->		N/A	0	9	6	2	6	10	3	0	9	3	1		

* Note that difficulty ranking was established purely from ranking the average distances. Additionally, checkpoints 1 and 15 were not factored into the checkpoint difficulty ranking because all subjects began at checkpoint 1 and not all subjects were able to complete the route, thereby never attempting to navigate to checkpoint 15.

** Note only checkpoints 2 through 14 were factored into this average because all subjects began at checkpoint 1 and not all subjects were able to complete the route, thereby never attempting to navigate to checkpoint 15 from the previous checkpoint.

*** Number of checkpoints flown within the subject pool's 260 meter threshold as established by question #22 of the questionnaire.

Table 2. Subject pool's proximity to each checkpoint.

Figures 37 and 38 are charts representing possible correlation between empirical and subjective performance metrics. Both charts have been normalized in scale and exhibit each subject's performance according to specific metrics.

Correlation A shows the correlation between the subject pool's 260-meter threshold derived from the questionnaire before they flew the route and the subject

pool's total acceptable performance ratings from the peer evaluations after they flew the route.

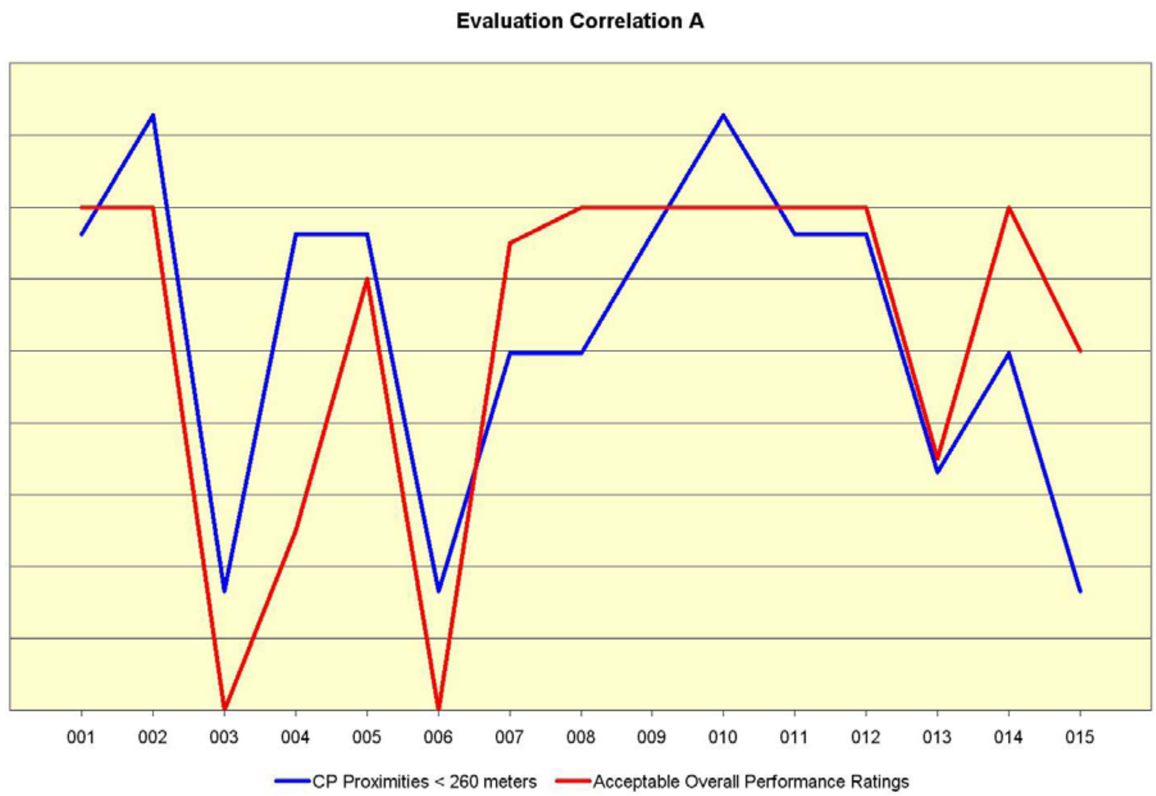

Figure 37. Evaluation Correlation A.

Correlation B shows the correlations between estimation differences for both heading and position and the subjective judgments of the subject pool's peer evaluations as well as the subject pool's overall acceptance of each subjects performance.

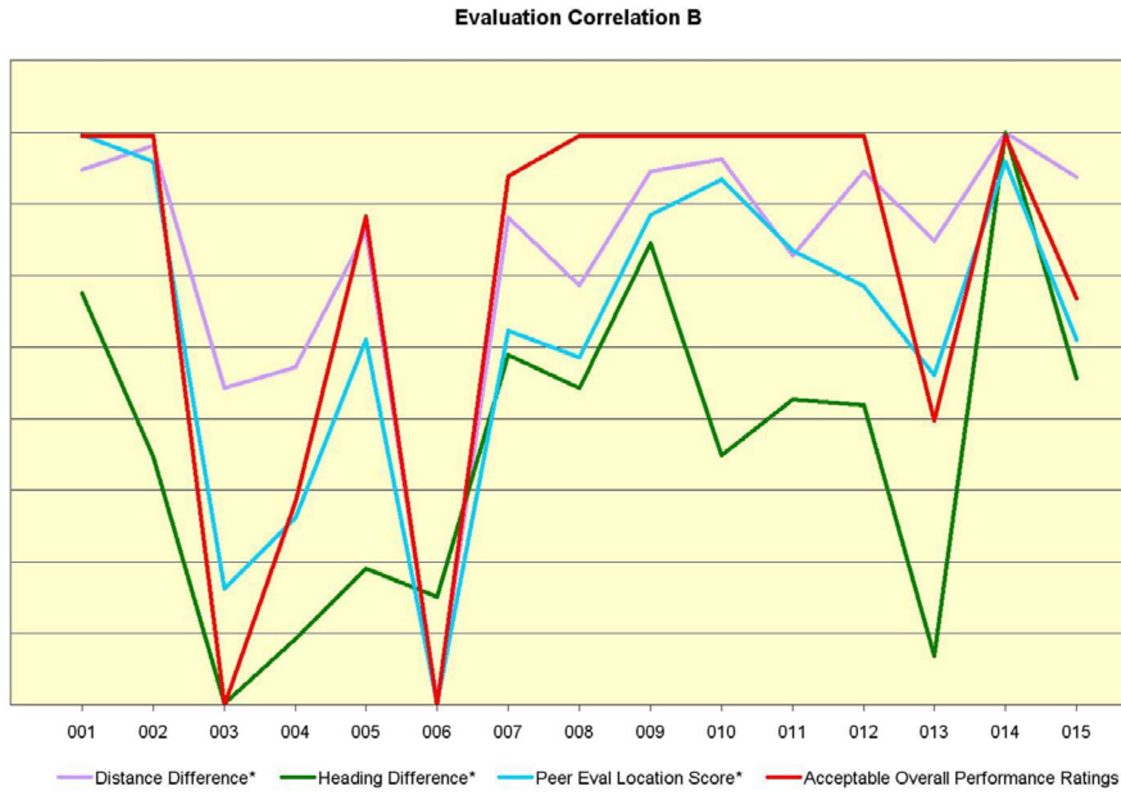

Figure 38. Evaluation Correlation B.

The subjects were asked to estimate there percentage of time their gaze was spent looking in each sector (question 49 of the questionnaire in Appendix B). Figure 38 depicts estimations of actual flight while figure 39 depicts estimations while using the ChrAVE. The numbers suggest that the ChrAVE is less effective in providing information to the user via the chin bubble and far right gaze than in the actual flight. There are a few theories for this shortcoming. First, the lighting in these areas was difficult to smoothly light resulting in shaded augmented graphics in the user’s view. Second, the umbilical of cables coming off of the back of the headgear was prohibitive to movement in these sectors. And lastly, given only fifteen subjects and their best recollection of their gaze habits, these differences are insignificant and should be examined in a more scientific manner.

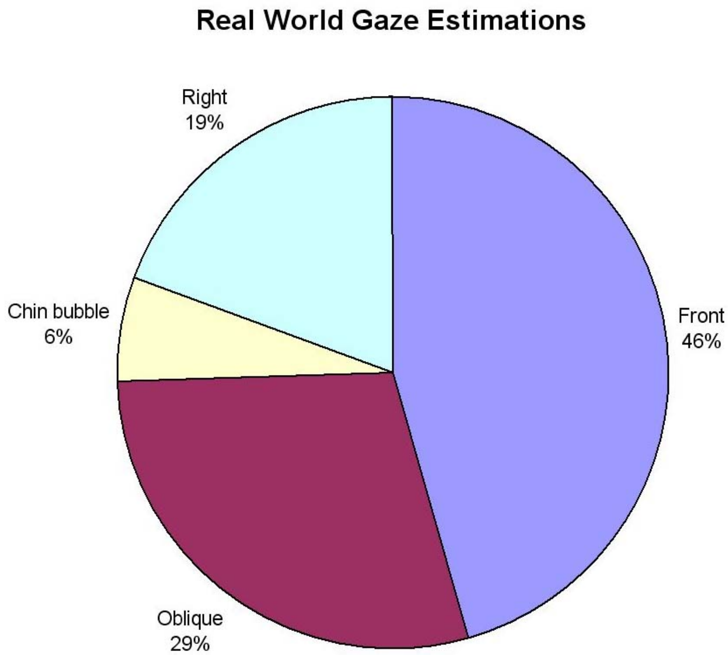

Figure 39. Gaze direction estimations while flying actual aircraft during low-level land navigation.

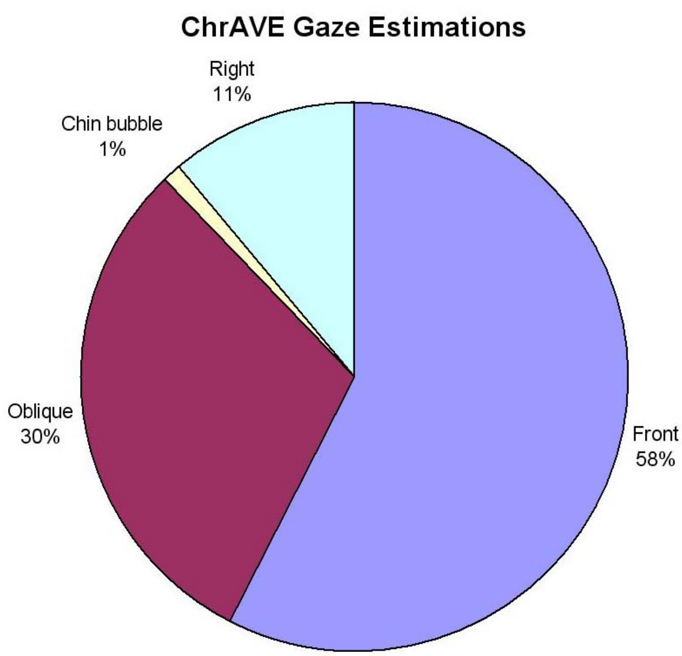

Figure 40. Gaze direction estimations while using the ChrAVE for low-level land navigation.

VII. CONCLUSIONS

The overall goal of the ChrAVE prototype system is twofold:

1) To place the subject in an immersive and familiar environment, true in first person fidelity with as few physically imposed distractions as possible.

While the ChrAVE was both an immersive and highly familiar helicopter setting for the subject pool, it was not nearly as true in first person fidelity. The immersive nature of the system during task performance suggests that mentally first person fidelity may have been fully achieved even though physical first person fidelity was generalized for any helicopter navigational task. Perhaps true first person fidelity can be achieved by appending the ChrAVE onto a given pilot's specific type/model/series aircraft.

2) To exercise the task of navigation as faithfully and rigorously as the task is in the real world.

Observation of the subject pool along with their performance and comments suggest that the ChrAVE was successful in replicating the task of navigation. That said, there are still interface and visual improvements that should be made to enhance the experience.

While motion parallax and coincident FOV is optimized shortcomings in the visual presentation remain. Visual shortcomings in the present system appear to inhibit or delay the user's information gathering ability. This disruption makes the user work harder to perform the normal task of day VFR flight. Improvements made to the visual

presentation of the system will likely reduce the workload to that expected in actual day VFR flight.

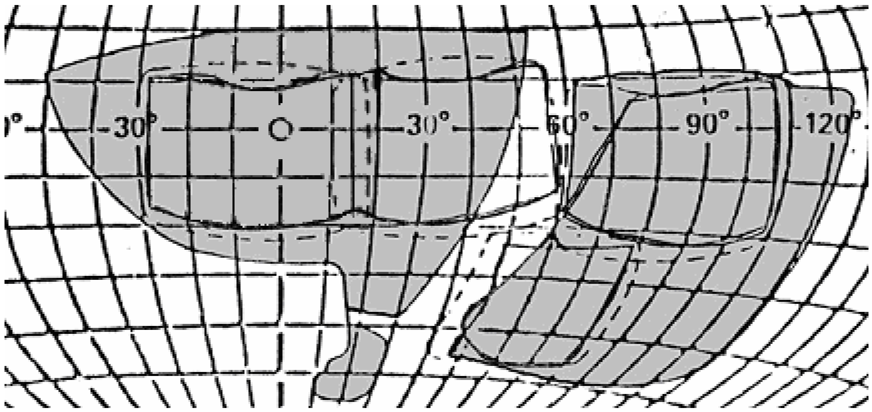

Figure 41. Coincident fields of view available in SH-60F (light gray) and the ChrAVE system (also light gray) due to no change in pilots head movement behavior. Adapted from (Sikorsky, 1989).

The average length of time since the last low-level navigation flight for the subject pool was nineteen months. Skill degradation of the subject pool since their last flight is not reportable since no performance data from the subject pool’s active flying history was available to this study; we can only assume the subject pool would have a heightened skill set if they were flying on a daily basis.

In summation, this research, while fertile for follow-on focused research from a human interface and task performance standpoint, has proved successful. The ChrAVE remains a viable system for navigational training and the acquisition of spatial knowledge. As such, the ChrAVE should continue to be improved and explored.

VIII. FUTURE WORK

It appears that future versions of the ChrAVE have a multitude of facets and features to improve on. Because of the inherent modularity of the ChrAVE system, improvements of one part can be contained within a given module, yet benefit the overall product.

Possible ChrAVE subsystems that lend themselves to immediate future work are:

-Improved headgear assembly and ergonomics. Reducing ELD, providing for a more realistic FOV and (variable) focal length would result in a more-natural presentation to the user. Modeling the headgear to mimic the present helmets and NVGs would appear to be the most logical design to pursue.

-Migrate outside VE view and instrument panel rendering to a single CPU. As chip speeds increase it may be both economically and ergonomically advantageous to render the far field VE view and the instrument panel to separate windows and channels within the software application. However, considering the ultimate goal is to append the ChrAVE system onto an existing aircraft, the 'rendering' of and instrument panel would be replaced with producing appropriate signals to drive existing implementation.

-Migrate the chromakey mixing to the video processing unit (VPU). If all camera and VE signals could be mixed on a VPU, the need for an external mixing unit and many of the signal conversion units would negated, thereby reducing the

overall expense of a ChrAVE system. Additionally, the reduction in signal conversion throughout the systems pipeline means less error propagation in the final presentation.

-Improve chromakey camera reception. Technological limitations and recent advancements dictate that there be a movement from traditional bluescreen backdrops to a LiteRing™ (light emitting diodes (LEDs) mounted around the camera lens) and Chromatte™ material (a material impregnated with microscopic reflective glass beads). When used in concert the LiteRing™ emits chromakey blue light that is reflected off of the Chromatte™ material back to the lens. This technology does away with the need for problematic and costly lighting equipment specific to backdrop lighting. Additionally, such technology may lend itself to accomplishing dark cockpit, NVG type, navigation in the ChrAVE since the camera does not require any extra illumination.

Beyond the ChrAVE system there are a number of questions this research stirred up that would be excellent fodder for future work.

-Objective performance metric development. Commonsense drove the primitive metrics presented in this study. This study embraced the resident expert knowledge of the subject pool as well as empirically derived data to illustrate a subject’s performance relative to the rest of the pool. Clearly, more sophisticated data gathering and metric development techniques will provide a clearer indication of user performance while maintaining objectivity. Additionally, it may be possible to gain

insight into the user’s state of mind as they try to navigate. By comparing an intended route of flight to a user’s virtual route of flight, physical proximity performance can be established. But by comparing a user’s perceived route of flight (a path indicating a navigator’s perception of where they flew) to his virtual route of flight, it is hypothesized that a perceptual proximity performance can be established. Comparing the two types of proximity may establish why a performance was successful or not. Did the navigator know where they were, or were they just lucky? If the navigator knew where he was, why was he off the intended route of flight? These questions may be able to be answered.

- Networked VEs in collaborative efforts.

Allowing multiple aircrews to work as a flight could benefit the tasks of form and tactical flight, and the roles inherent in those tasks. Additionally pilots could exercise sound cover and concealment techniques in low-level navigation be playing hide & seek.

-Further viability testing for a ChrAVE deployed aboard naval vessel.

What will be the effects of flying a motionless immersive trainer, such as the ChrAVE, on a ship that is subject to the movements of the sea? Will a cyber/motion sickness emerge or will prolonged exposure force the pilots to divorce the seat of the pants feelings from their visual perceptions?

Much like its cousin the CAVE, the ChrAVE may prove to be a valuable platform from which to launch many human-computer interface (HCI) experiments.

Can a ChrAVE system set in the confines of a cockpit be used by a navigating pilot to sufficiently provide that pilot with spatial knowledge of an area of flight prior to ever having flown there? Clearly there is a difference between ‘knowing’ an area and navigating through or about an area. Knowing an area is the product of temporal and spatial interactivity exposures, while navigating is the process of mental calisthenics during interactivity exposures. More specifically, navigation is the method of determining position, course, distance passed over, etc. Knowing an area means intuitively knowing or recognizing your position, relative course and distance to other positions. Terrain association is clearly important her, but to what degree?

Vallino’s suggests, “the primary performance goal for the virtual reality system is to present visual stimuli that are consistent with the changes in body position sensed by the user.” The same can be said for AR, however the ChrAVE is not a motion based platform system. Because the user is consumed with an inside out view of the virtual world while flying the ChrAVE, the user would expect a natural connection between the user’s internal proprioceptive coordinate system and the virtual world coordinate system. Considering the goal of this research is to ultimately embed a ChrAVE-like system in an aircraft embarked on a naval vessel, one can quickly ascertain that proprioceptive registration or fusion will be challenging.

Will this strengthen a pilot’s trust in the instrumentation during instrument flight? Will this aid pilots in developing skills to consciously divorce (seat of the pants) information from their own proprioceptive system when relying on instruments to fly?

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LIST OF REFERENCES

Azuma, R. & Baillot, Y. & Behringer, R. & Feiner, S. & Julier, S. & MacIntyre, B. (2001). *Recent Advances in Augmented Reality*. [WWW Document]. URL http://www.cs.unc.edu/~azuma/cga2001.pdf.

Chief of Naval Operations (1992). NWP 55-9-ASH, Vol. I (Rev. F) FMFM 5-35 *Assault Support Helicopter Tactical Manual*. Washington, DC: Government Printing Office.

Dvorine, I. (1963). *Dvorine Pseudo-Isochromatic Plates.* Baltimore, MD: Waverly Press, Inc.

Fischer, R.E. & Couture, M.E. & McGuigan, W.G. (2002). *Effective Use of Off-The-Shelf Optics has Many Facets.* Laser Focus World, 38(1), pp. 139-144.

Flight Link Inc. (2001). [WWW Document]. URL http://www.flightlink.com/hardware/rotorwing/index.html.

Flo Co, Inc. (2001). [WWW Document]. URL http://www.flo-co.com.

InterSense Inc. (1999). IS-600 Series Precision Motion Tracker User Manual. Burlington, MA.

InterSense Inc. (2001). [WWW Document]. URL http://isense.com/products/prec/is600/is600plus.pdf.

Matsushita Electric Corporation of America (2002). [WWW Document]. URL http://www.panasonic.com/medical_industrial/gpus532.asp.

McLean, T.D. (1999). *An Interactive Virtual Environment for Training Map-Reading Skills in Helicopter Pilots*. Unpublished master’s thesis, Naval Postgraduate School, Monterey, CA.

Melzer, J. E. & Moffitt, K. W. (1997). *Head Mounted Displays. Designing for the User.* New York, NY: McGraw-Hill.

Micheletti, J. D. & Wurpts M. J. (2000). *Applying Chroma-Keying Techniques in a Virtual Environment.* Southwest Research Institute, P.O. Drawer 28510, San Antonio, TX. [WWW Document]. URL http://www.tss.swri.edu/pub/pdf/2000AEROSENSE_HMD.pdf

Mole-Richardson Co. Inc. (2001). [WWW Document]. URL http://www.studiodepot.com/store.

Pelco (1999). [WWW Document]. URL ftp://www.pelco.com/ProductSpecs/2752.PDF

Richmond Products Inc. (2001). *Dvorine Technical Articles*. [WWW Document]. URL http://www.richmondproducts.com/dvorine_technical_articles.htm.

Smith, W. J. (2000). *Modern Optical Engineering.* New York, NY: McGraw-Hill.

Sullivan, S. R. (1998). *Helicopter Terrain Navigation Training Using a Wide Field of View Desktop Virtual Environment*. Unpublished master's thesis, Naval Postgraduate School, Monterey, CA.

Ultimate Corp. (2000). *Ultimatte-400 Deluxe Operating Manual.* Chatsworth, CA.

Vallino, J. R. (1998). *Interactive Augmented Reality*. Unpublished doctoral dissertation, University of Rochester, Rochester NY.

Virtual Research. (2000). [WWW Document]. URL http://www.virtualresearch.com/index.html

Wright Jr., G. T. (2000). *Helicopter Urban Navigation Training Using Virtual Environments*. Unpublished master's thesis, Naval Postgraduate School, Monterey, CA.

APPENDIX A. HARDWARE SPECIFICATIONS

A. V8 HEAD MOUNTED DISPLAY FROM VIRTUAL RESEARCH SYSTEMS

Display	• Dual 1.3” diagonal Active Matrix Liquid Crystal Displays • Resolution per eye: ((640x3)x480), (921,600 color elements) equivalent to 307,200 triads • Contrast ratio: 200:1
Optical	• Field of view: 60° diagonal • Multi-element glass, fully color corrected design • Interpupillary distance (IPD) range: 52mm to 74mm • Eye relief: Adjustable 10-30mm design accommodates glasses • Rubber eye cups prevent eyeglasses and lens contact • Overlap: Standard 100%
Audio	• Sennheiser HD25 high performance headphones • Headphones rotate above headband and snap off when not in use
Mechanical	• Single rear ratchet allows for quick, precise fit • IPD assembly moves fore/aft to accommodate glasses • IPD knobs accessible at sides of shell • HMD overall length/width/height: 17.5” x 8” x 6” (43 x 20 x 15 cm) • HMD Weight: 34 ounces (1.0 kg)
Cable	• Description: Custom molded cable • Length 13’ (3.9m) standard • Connector: 50 pin SCSI
Control Box	• VGA (640 x 480 60Hz) input format • Sync on green, separate H and V, or Composite (+ or - going) • Overall brightness and contrast • Stereo or mono input auto detected • Mono input drives right and left eye with one signal • Audio Input: 3.5mm mini stereo phone jack • Monitor Output: VGA (640 x 480 60Hz)
Electrical	• Power supply: Universal input (+5, +24, -12, VDC) output • Power consumption: 30W

B. GP-US542 3-CCD HIGH PERFORMANCE MICRO HEAD COLOR CAMERA WITH DSP FROM PANASONIC

TV System	NTSC (Available in PAL)
Pick-up System	Micro prism system
Pick-up Device	768 (H) x 494(V) Three 1/3" interline transfer (IT) supper high sensitivity CCDs
Scanning System	2:1 Interlace 525 lines, 60 fields, 30 frames Horizontal: 15.734kHz, Vertical: 59.94Hz
Synchronizing System	Internal or External (Gen-Lock)
• Internal	NTSC standard (Available in PAL as GP-US532E***)
• External (Gen-Lock) Input	VBS, VS, HD/VD SC Phase for Gen-Lock (VBS): Free adjustable over 360 H Phase for Gen-Lock (VS): Adjustable
Video Outputs	
• Video 1,2	1.0V [p-p] / 75 ohms NTSC composite video signal, BNC Connector
• S-VIDEO (Y/C) Out	(Y) 0.714V [p-p] / 75 ohms (C) 0.286V [p-p] / 75 ohms, S-VIDEO Connector x 1
• RGB/SYNC	(R/G/B) 0.7V [p-p] each / 750 (SYNC) 4V [p-p] / 75 ohms or 0.3V [p-p] 1750 selectable, D-SUB 9-pin Connector x 1
Required Illumination	2000 lx at F8.0 3200K
Minimum Illumination	9 lx (0.9 foot candle) at F2.2 with +18db gain, 30 IRE level
Signal-to-Noise Ratio	62dB (Typical, Luminance) without aperture and gamma
Horizontal Resolution	750 lines at center (Y signal)
White Balance	ATW (Automatic Tracing White Balance Control), AWO (Automatic White Balance Control) and Manual
Black Balance	ABC (Automatic Black Balance Control) and Manual
Color Bar	SMPTE color bar with 7.5% set-up
Electronic Shutter	ELC (Electrical Light Control) and Manual STEP: Selectable 1/60 (OFF), 11100, 1/250,1/500, 1/1000, 1/2000, 1/4000, and 1/10,000 sec SYNCHRO SCAN: Selectable from 1/525 to 254/525 line
Gain Selection	AGC, Manual Gain (0, +9, +18db Selectable)
Switches	Power On/Off (POWER), Camera/Color Bar Selection (CAM/BAR), Gain UP Selection (OFF/LOW/HIGH (0/+9/+18dB), White Balance Selection (ATW/AWC/MANU), ELC (Electronic Light Control) On/Off, PAGE, ITEM (AWC) <(ABC) and> Scene 1/2
Controls	R Gain, B Gain and ELC LEVEL
Computer Interface	RS-232C Control, D-SUB 9-pin Connector x 1
Lens Mount	C Mount

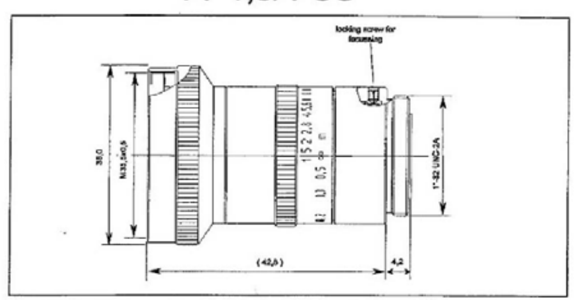
Power Source	12V DC
Power Consumption	8.4 W
Ambient Operating Temperature	32F - 113F (0C - 45C)
Ambient Operating Humidity	30%-90%
Dimensions	
• **Camera Head (Excluding Mounting Adapter)**	34 (W) x 44 (H) x 52 (D) mm [1-5/16" (W) x 1-11/16" (H) x 2" (D)]
• **CCU (Excluding Rubber Foot and connector)**	206.5 (W) x 44 (H) x 250 (D) mm [8-1/8" (W) x 1-11/16" (H) x 9-1/2" (D)]
Weights • **Camera Head:** • **CCU:**	 110g (0.24 lbs) 1.7kg (3.74 lbs)

C. LENSES

1. TV 1,5/4 C From Doctor®

Type	Manual Lockable
Format Sizes	Up to 1/3-inch
Mount Type	C
Focal Length	f = 4.2mm
Max. Rel. Aperture	K_{max} = 1.5
Image Diameter	2Y' = 6mm
Angle of View	2σ = 72
Number of Elements	7
Number of Groups	7
Back Focal Length	s'F' = 13.5mm
Front Focal Length	sF = 15.1mm
Cumulative Lens Thickness	Σ_d = 45.6mm
Pupil Distances	S_{EP} = 15.7mm

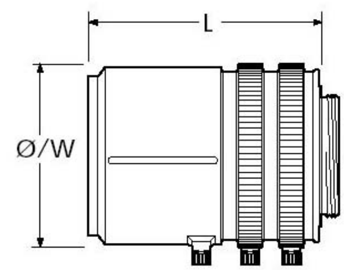
DOCTER® TV 1,5/4 C
TV 1,5/4 CS



Pupil Diameters	S'_{AP} = -15.7mm $\varnothing_{EP}$ = 2.76mm $\varnothing_{AP}$ = 19.47mm
Mount	C CS with adapter
Mounting Depth	4.2mm
Focus Range	e = 0.15m…∞
Unit Weight	.77 / 90g

2. 12VA6-13 ½-inch Format Varifocal Lens from Pelco

Type	Varifocal
Format Sizes	1/2-inch 1/3-inch
Mount Type	C
Focal Length	6-13mm
Zoom Ratio	2.2X
Relative Aperture (F)	1.8-Close
Operation	
• **Iris**	Manual
• **Focus**	Manual
• **Zoom**	Manual
Angle of View	
• **Diagonal**	35.5-75.5
• **Horizontal**	28.5-60.3
• **Vertical**	21.4-45.2
Minimum Object Distance	0.3m
Back Focal Length	8.7mm
Filter Size	N/A
Unit Weight	.20 lb (.09 kg)



	Ø/W	L
12VA6-13	1.65 (42.00)	1.91 (48.60)

D. IS-600 MARK 2 MOTION TRACKER FROM INTERSENSE™

Maximum Angular Rate	1200°/sec
Angular Resolution	0.02° RMS
Angular Accuracy	0.25° RMS
Maximum Linear Velocity	15'/sec
Translation Resolution	0.01" RMS

Translation Accuracy	0.25” RMS
Prediction	0-50ms
Number of InertiaCube Sensors	Up to 4
Number of SoniDisc Beacons	Up to 8
Orientation Update Rate	Up to 500Hz
Position Update Rate	Up to 150Hz
Interface	RS-232C with selectable baud rates to 115,200
Protocol	Compatible with industry-standard protocol (FASTRAK™)
Max. System Configurations	GEOS: 4 orientation-only stations; PULSAR: 8 position-only stations; DUAL: 4 6-DOF stations; FUSION: 4 6-DOF stations Or any combination of Operating Modes that Make use of 4 InertiaCubes and 8 SoniDiscs
Power	100-240 VAC, 1.0A, 50-60W
Fusing	100-120 VAC: T250V, 1.0A 220-240 VAC: T250V, 0.5A
Operating Temperature	0 to 50C (32F to 122F)
Storage Temperature	-20 to 70C (-4F to 158F)

	Dimensions	Weight	Cable
InertialCube orientation sensor	1.06” x 1.34” x 1.2”	2.1 oz.	10’ extendible to 30’
SoniDisc position sensor	1.0” x 1.0” x 0.65”	0.4 oz.	n/a
X-bar	41.4” x 3.0” x 1.7”	8.2 lb.	20’ extendable to 34’*
ReceiverPod (each)	4.75” x 3.0” x 1.7”	0.8 lb.	24” extendable to 34’*
Base Unit Signal Processor	16.75” x 12” x 4”	8.4 lb.	n/a

*Total X-bar plus ReceiverPod cable length not recommended to exceed 40’

Compatibility	The InterSensevIS-600 Mark 2 is compatible with all the industry leading software and hardware

Virtual Research	Superscape	Sense8	Meta VR	Division
Thomson T&S	Softimage	Multigen	nVision	Xtensory
Kaiser Electro-Optics				

E. VSC 200D VIDEO SCAN CONVERTER FROM EXTRON ELECTRONICS (VGA TO D1)

Video Input	
• **Number / Signal Type**	1 VGA, 1 Mac RGBHV, RGBS, and RGsB
• **Connectors**	VGA 1 15-pin HD female + adapter cable

	Mac 1 15-pin D female
• **Nominal Level(s)**	Analog 0.7V p-p
• **Minimum / Maximum Level(s)**	Analog 0V to 2.0V p-p with no offset
• **Impedance**	75 ohms or High Z (switchable)
• **Horizontal Frequency**	Autoscan 24 kHz to 811 kHz
• **Vertical Frequency**	Autoscan 50 Hz to 120 Hz
• **Resolution Range**	Autoscan 560 x 384 to 1280 x 1024
• **External Sync (Genlock)**	0.3V to 1.0V p-p
Video Processing	
• **Encoder**	10 bit digital
• **Digital Sampling**	24 bit, 8 bits per color; 80 MHz
• **Colors**	16.8 million
• **Horizontal Filtering**	4 levels
• **Vertical Filtering**	5 levels
• **Encoder Filtering**	3 levels
Video Output	
• **Number / Type / Format**	1 RGBHV / RGBS / RGsB or component video or 1 digital component video (CCIR 6011 / ITU-R BT.601)(VSC 200D only), or 1 S-video, or 1 NTSC / PAL composite video
• **Connectors**	5 BNC female — 1 RGBHV / RGBS / RGsB or component video 1 BNC female — 1 digital component video -- VSC 200D only 1 4-pin mini-DIN female — S-video 1 BNC female — composite video
• **Nominal Level**	RGBHV / RGBS / RGsB — 0.7V p-p S-video and composite — 1.0V p-p
Impedance	75 ohms
Sync	
• **Input Type**	Auto detect RGBHV, RGBS, and RGsB
• **Output Type**	RGBHV, RGBS, and RGsB (all RGB formats are swith selectable)
• **Genlock connectors**	1 BNC female — genlock input 1 BNC female — genlock output (terminate w / 75 ohms if unsed)
• **Standards**	NTSC 3.58 and PAL
• **Input Level**	1.5V to 5.0V p-p
• **Output Level**	5V p-p
• **Input Impedance**	75 ohms

- **Output Impedance** 75 ohms
- **Polarity** Negative

F. ADC-6801 SIGNAL CONVERTER FROM LEITCH (RGB TO D1)

Input		
• **Sampling Rate**	27MHz Y 13.5MHz Cr/Cb	
• **Quantization**	10 bits	
• **Input Standards**	SMPTE / EBU, MII, Betacam component or RGB at 525 or 625 lines rates	
• **5 BNCs**	Ext. Sync, Loop Through G/Y, B/B-Y, R/R-Y	
Component Analog Input		
• **Connector**	BNC per IEC 169-8	
• **Impedance**	75 ohms unbalanced	
• **Signal Level**	1 V	
• **Adjustable Gain**	±10%	
• **Time Adjustment Range**	±1.8µs	
• **Return Loss**	>40dB to 5.5 MHz	
Filtering As Per CCIR 601 Specifications		
• **Frequency Response**	Y channel	±0.1 dB to 5.5 MHz
	Cr, Cb Channels	±0.2 dB to 2.75 MHz
• **Signal to Noise Ratio on all Channels**	>64 dB RMS, relative to 0.714 V, 10 kHz to 5.5 MHz	
• **Interchannel Crosstalk**	<-50dB	
• **2T K factor**	<0.5%	
• **Luminance Non-linearity**	<1%	
• **Gain Alignment**	<1%, typically better than 0.5%	
• **DC Clamping**	Typically within 1 quantization level on field average.	
Output		
• **Output Standard**	4:2:2, two BNCs as per SMPTE 259	
• **Input to Output Delay**	3.6µs	

G. ULTIMATTE 400-DELUX COMPOSITE VIDEO MIXER FROM THE ULTIMATTE CORPORATION

Specifications	• Conforms to CCIR 601 • 10-bit or 8-bit SDI inputs and outputs • Internal Foreground and Matte processing 4:4:4:4 • 525 / 625 Auto-selectable

Video

• **I/O Resolution**	4:2:2
• **FG Input**	4:2:2
• **BG Input**	4:2:2
• **Matte In**	4:0:0
• **Digital Reference**	4:2:2
• **FG and BG Out**	4:2:2
• **Internal FG Processing and Matte Generation**	4:4:4:4
• **Inputs**	Serial CCIR 601, BNC 75
• **Outputs**	Serial CCIR 601, BNC 75

H. SDC-100 SERIAL DIGITAL TO VGA MONITORING CONVERTER FROM LEITCH (D1 TO VGA)

Serial Digital Input	BNC 75 ohm; 270Mb/s; 259M-C Up to 100m automatic cable equalization
Input Return Loss	13.9 dB at 270 MHz
VGA Monitor Output	Sub-D 15-pin female connector
RGB	±3 dB 0.7V, H+V TTL
Frequency Response	
• **Luminance**	±0.5 dB from DC to 5.25 MHz ±3 dB up to 10 MHz
• **Chrominance**	±3 dB up to 4 MHz
• **Gamma Correction**	Automatic
• **Standards**	525-line and 625-line auto switching
• **Signal-to-Noise**	-64 dB
625 line / 50 Hz mode with line doubling	
• **Horizontal Frequency**	31.25 kHz
• **Vertical Frequency**	50 Hz
525 line / 60 Hz mode with line doubling	
• **Horizontal Frequency**	31.469 kHz
• **Vertical Frequency**	59.94 Hz

I. VE CPU

Manufacturer / Model	Dell / Dimension 8100

CPU	Intel® Pentium® 4 1300 MHz
Memory	128 MB RAM
Operating System	Microsoft Windows 2000 5.00.2195 Service Pack 2
Monitor	Set to 640 x 480 for HMD compatibility 60 Hz
Power	Industry Standard for U.S. desktop computers

J. INSTRUMENT PANEL CPU

Manufacturer / Model	SGI / Silicon Graphics 320/540
CPU	X86 Family 6 Model 7 Stepping 2 SGI-320_ARCx86_mp
Memory	200 MB RAM
Operating System	Microsoft Windows 2000 5.00.2195 Service Pack 2
Monitor	SGI 1600 SW 60 Hz
Display Adapter Information	
• **Graphics Processor**	GeForce2 MX/MX 400
• **Bus Type**	AGP
• **Bios Version**	3.11.01.17.20
• **On-Board Memory**	32 MB
• **TV Encoder Type**	Conexant Bt869
Power	Industry Standard for U.S. desktop computers

K. TOP DOWN (PLOTTER) VIEW CPU

Manufacturer / Model	Dell / Dimension 4100
CPU	Intel® Pentium® 4 1300 MHz
Memory	128 MB RAM
Operating System	Microsoft Windows 2000 5.00.2195 Service Pack 2
Monitor	Set to 1024 x 786 60 Hz
Power	Industry Standard for U.S. desktop computers

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APPENDIX B. QUESTIONNAIRE & EVALUATION SHEET

ChrAVE Experiment & Questionnaire

***Please read first*:** The following experiment and questionnaire are completely confidential. Nothing you do or answer will be related back to you in any manner. Thank you for your assistance. Please begin below the solid line and hand to the proctor when you reach "Stop Here". You may ask questions at any time.

Subject Number _______ (proctor use only)

Preliminary questions:

1. Do you have any history of epilepsy? Yes / No
2. Are you prone to simulator sickness? Yes / No
3. Do you require corrective lenses? Yes / No
4. What is your vision uncorrected?
5. Do you have any other history of eye disease or injury?
6. How often do you use a computer on a daily basis? (Check one.)
   ❍ 0-2 hours ❍ 2-4 hours ❍ 4-6 hours ❍ 6-8 hours ❍ greater than 8 hours
7. Have you ever used virtual environment for training or entertainment? Yes / No
8. If yes, did you use a head-mounted display (HMD)? Yes / No
9. As a designated aviator, how would you rate your low level helicopter navigational skills? (Check one.)
   ❍ novice ❍ average ❍ advanced ❍ navigation instructor ❍ expert
10. List all type, model, series aircraft you are or have you been qualified to fly. (Disregard flight school aircraft unless you were a flight school instructor.)

    ____
    ____
    ____
    ____

11. About how many hours of flight time do you currently have? _________________
12. About how many hours of night vision goggle (NVG) flight time do you currently have? _________________
13. When was your last low level helicopter navigation map preparation?
    Month _________ Year _________

20. Are you familiar with Fort Irwin area depicted on the map issued to you for this experiment? Yes / No

If yes:
Have you ever flown in the area? Yes / No

The following questions ask your opinion of acceptable criteria for low-level navigation as it pertains to the terrain of the Fort Irwin area during non-tactical flight. You may refer to you map at any time.

21. Being within _____ meters of the intended route of flight is the threshold for acceptable and substandard navigational performance.
❍100 ❍200 ❍300 ❍400 ❍500 ❍600 ❍700 ❍800 ❍900 ❍1000 ❍More

22. Being within _____ meters of the intended checkpoints is the threshold for acceptable and substandard navigational performance.
❍100 ❍200 ❍300 ❍400 ❍500 ❍600 ❍700 ❍800 ❍900 ❍1000 ❍More

23. During flight between checkpoints it is acceptable for the route of flight accuracy threshold to decrease.
❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree

24. Number the following in order of importance:

______ Maintaining the route of flight
______ Accurately knowing your present location (plotting to 8 digit grid accuracy)
______ Accurately hitting your checkpoints
______ Being off the intended route of flight and intending to intercept at the next check point
______ Knowing your location by reference to a dominant terrain feature (plotting to 4 digit grid accuracy)
______ Seeing your checkpoints, but not hitting them
______ Being off the intended route of flight but working towards it.

25. Evaluation task:
You will be provided numerous map slides of the Fort Irwin area. The green path is the intended route of flight. Green circles are intended checkpoints. The black or red path is a recorded navigational performance. The black or red path is the where the subject flew. The black or red circles indicate where the subject identified the checkpoint. (Note that subjects not on the intended route of flight can still correctly identify a checkpoint and that subjects on the intended route of flight can mis-identify a checkpoint.) It is your task to separate these slides into acceptable and non-acceptable performance.

	B	D	F	G	I	K	M	N	P	Q	R	T	U	W	Y
Acceptable															
Non-acceptable															

3 Subject Number: ________

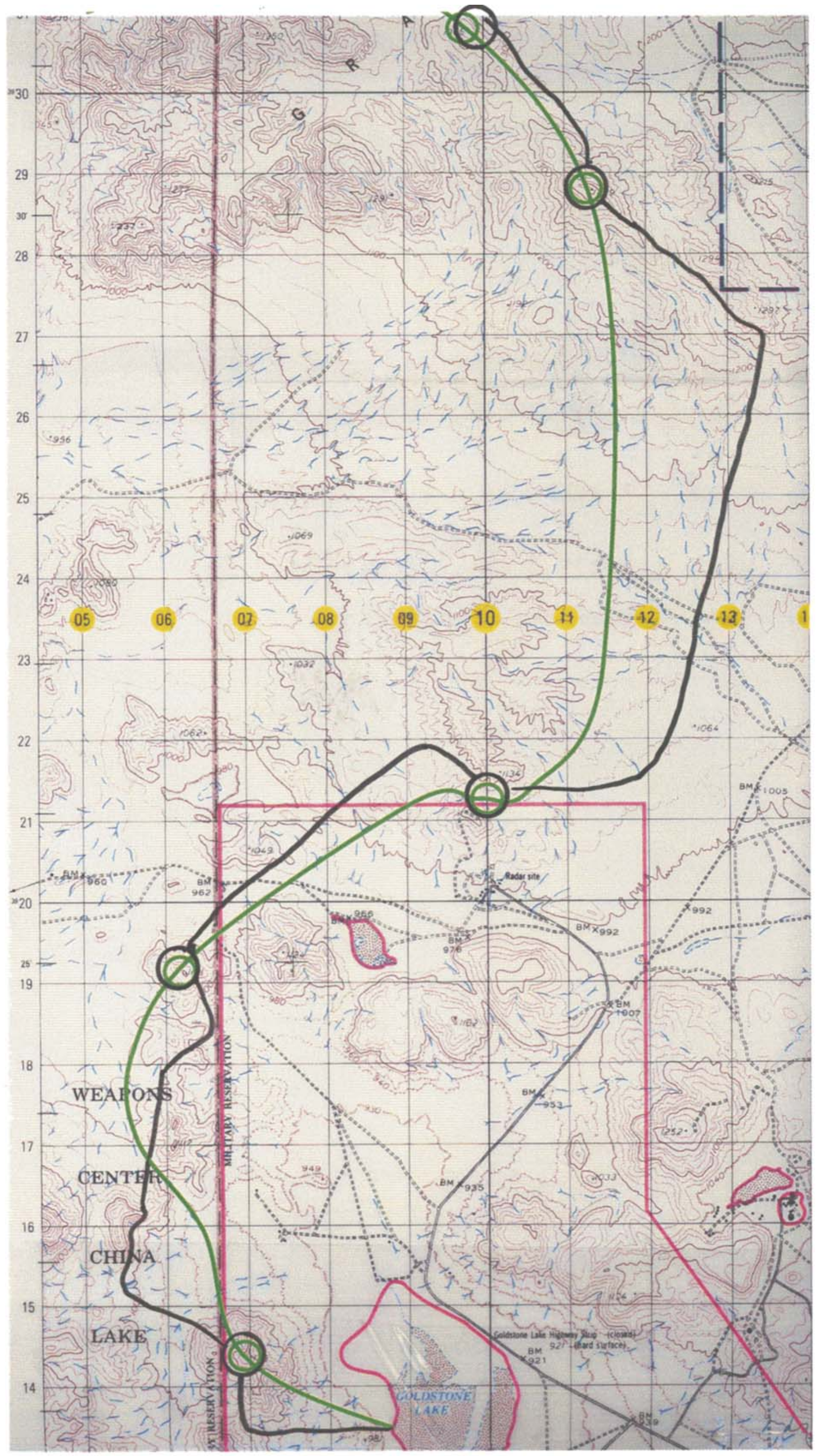


Figure 42. Evaluation Slide B.

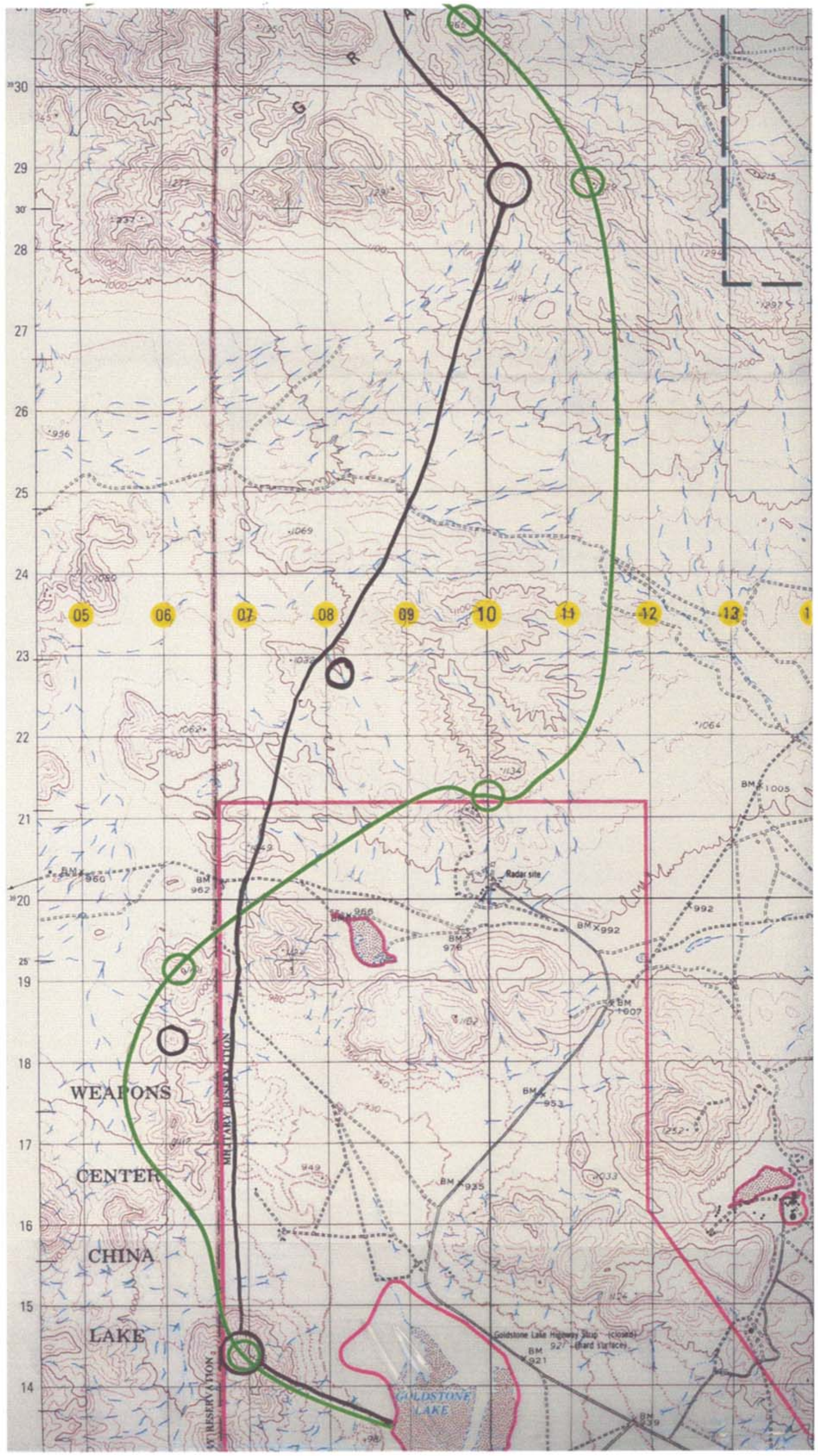


Figure 43. Evaluation Slide D.

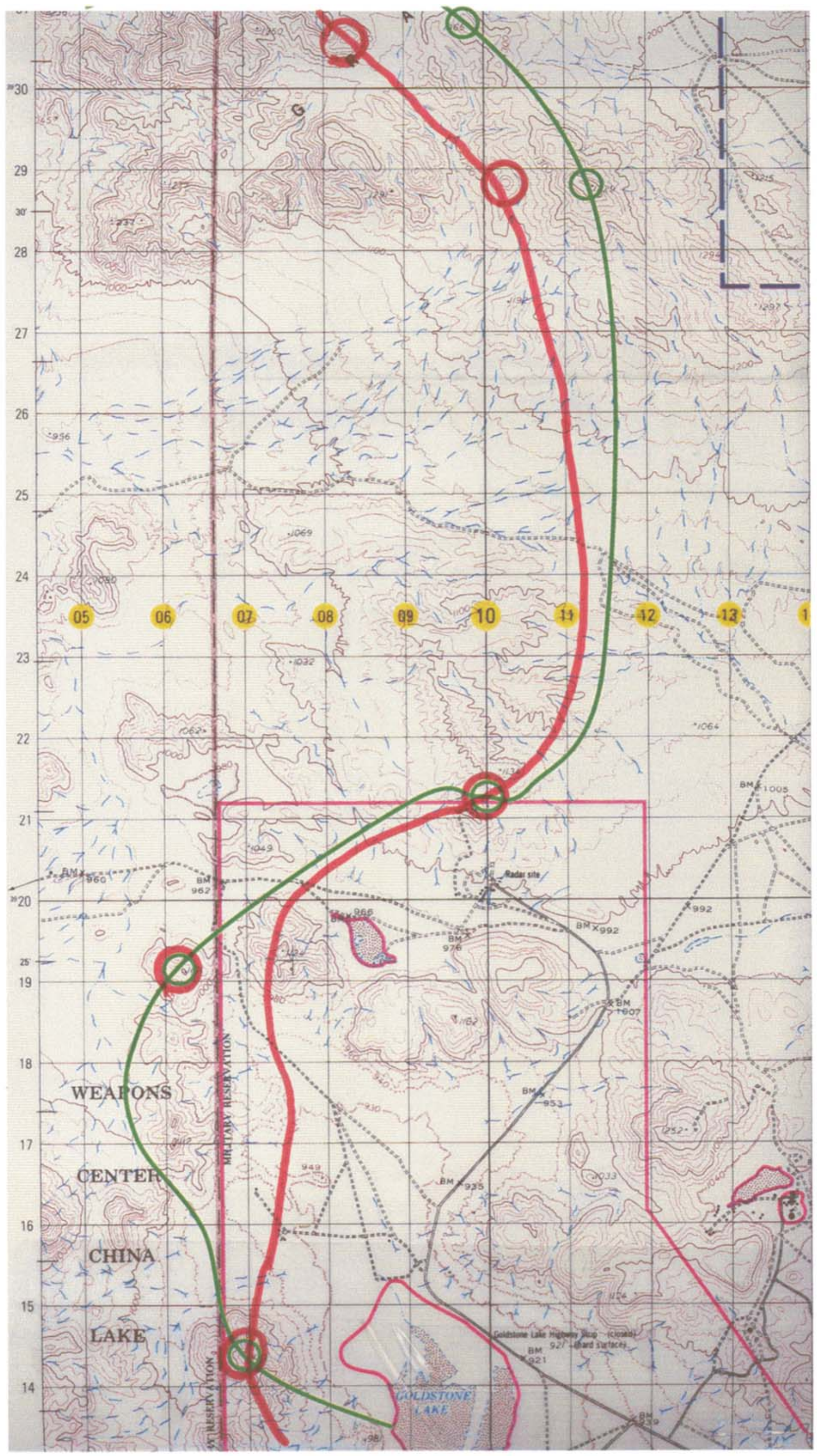


Figure 44. Evaluation Slide F.

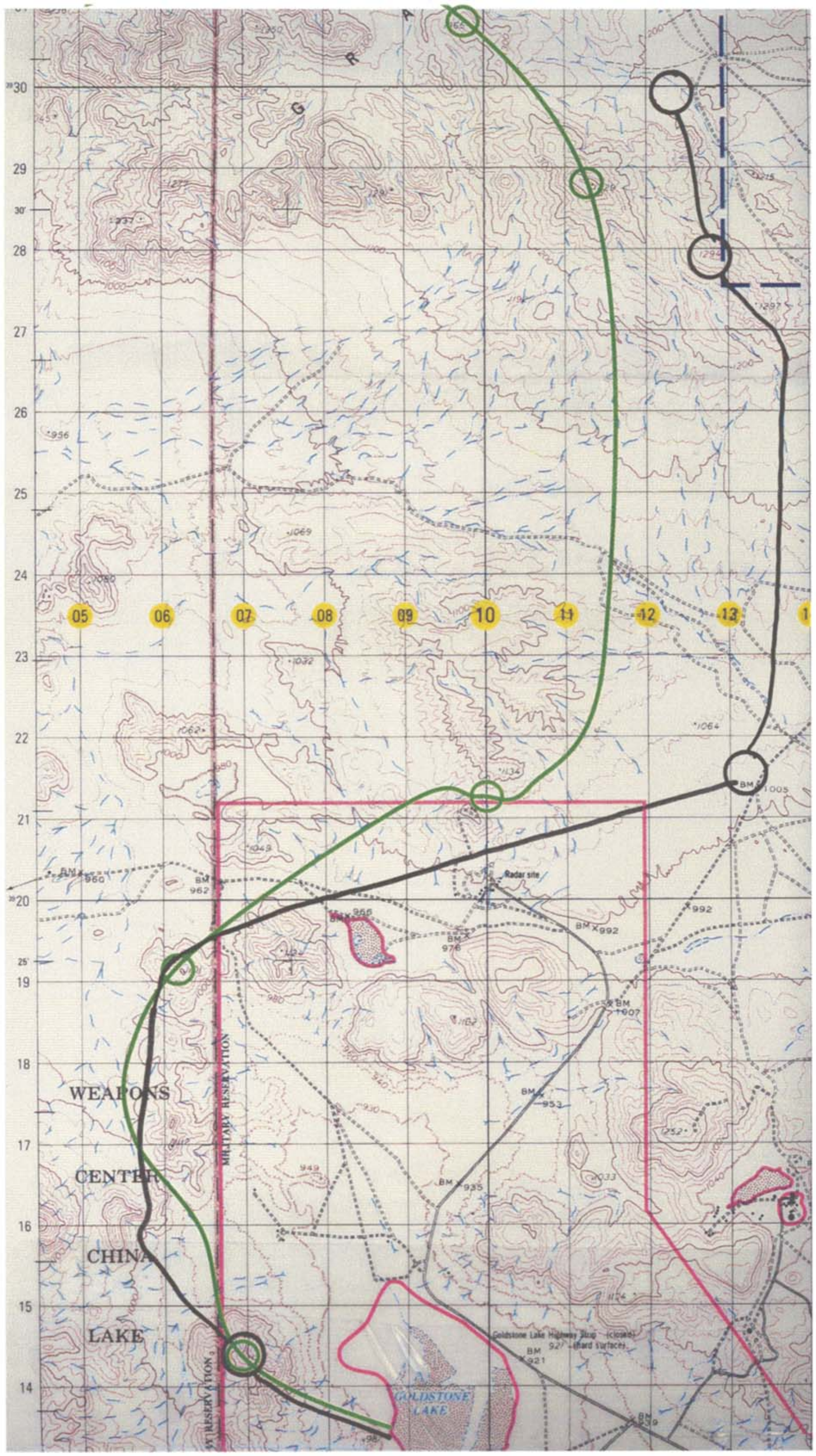


Figure 45. Evaluation Slide G.

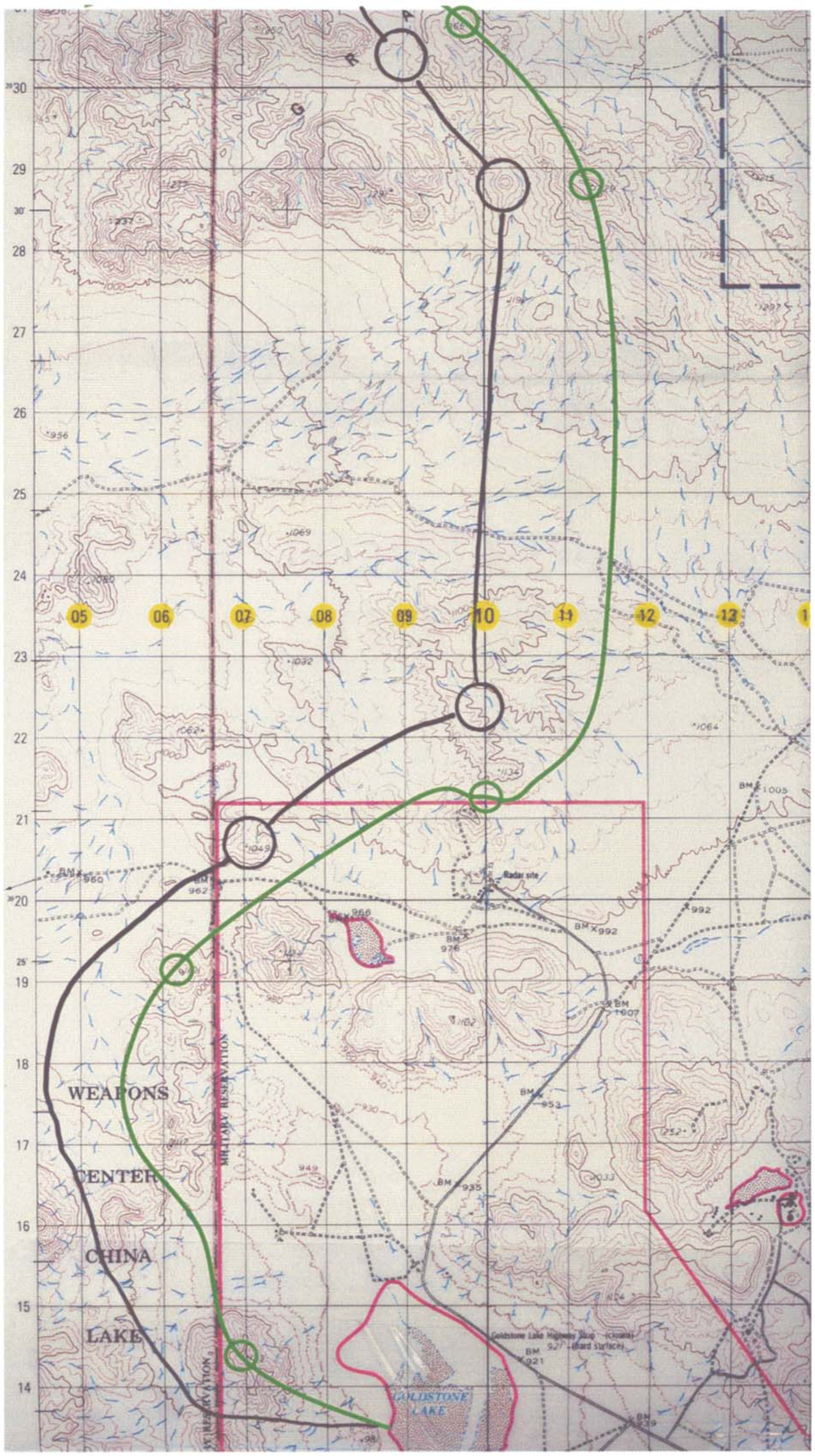


Figure 46. Evaluation Slide I.

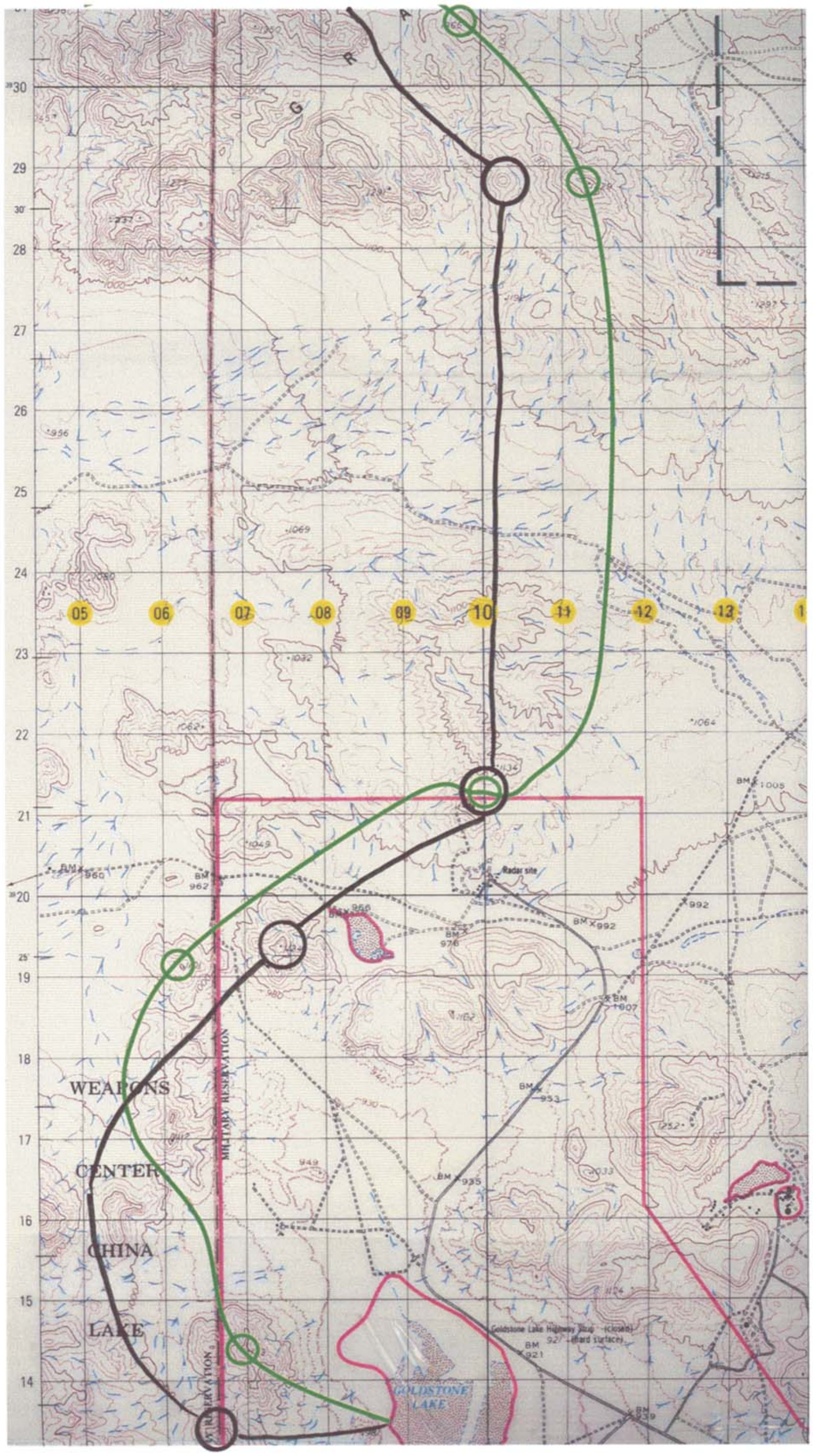


Figure 47. Evaluation Slide K.

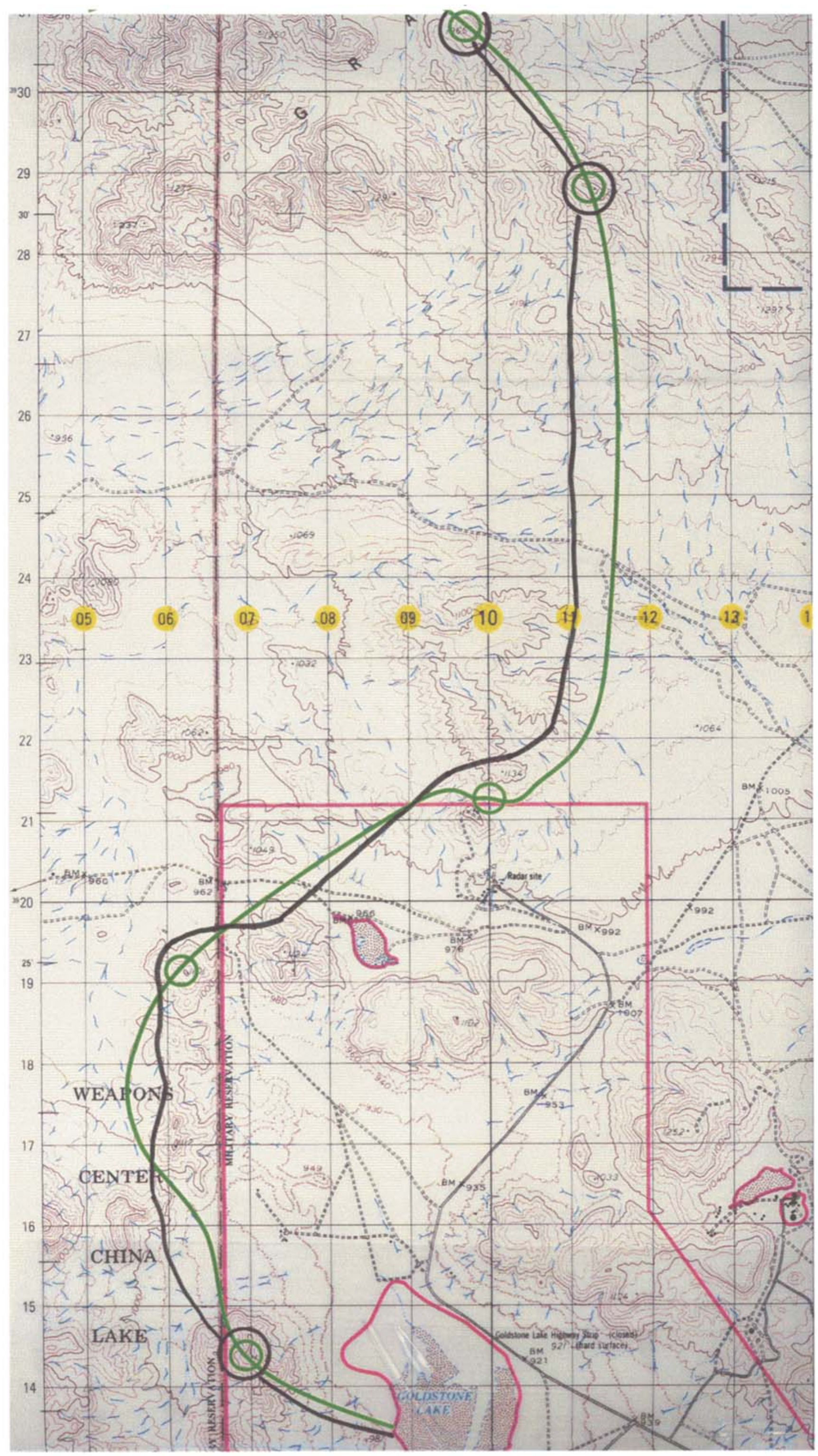


Figure 48. Evaluation Slide M.

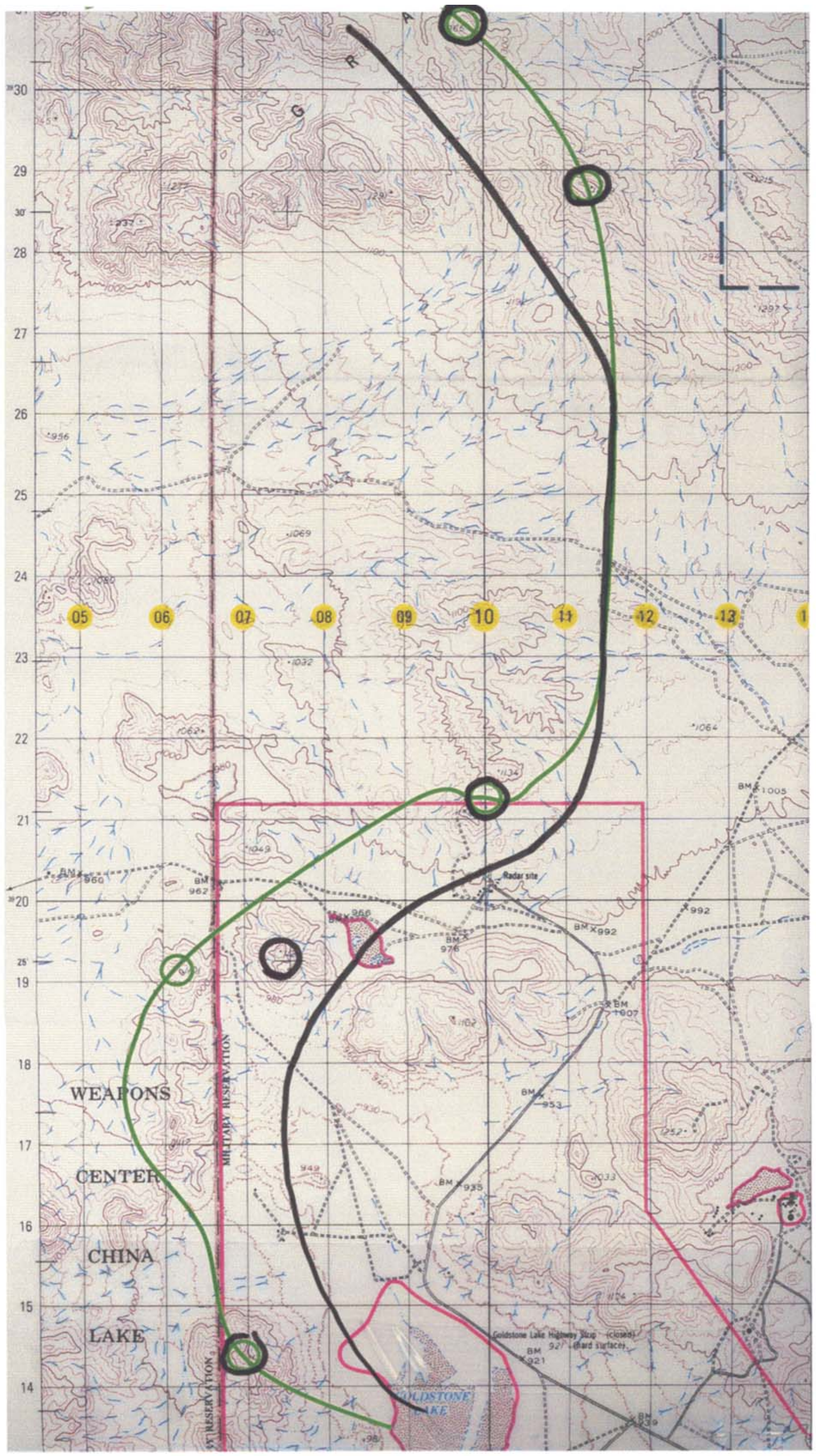


Figure 49. Evaluation Slide N.

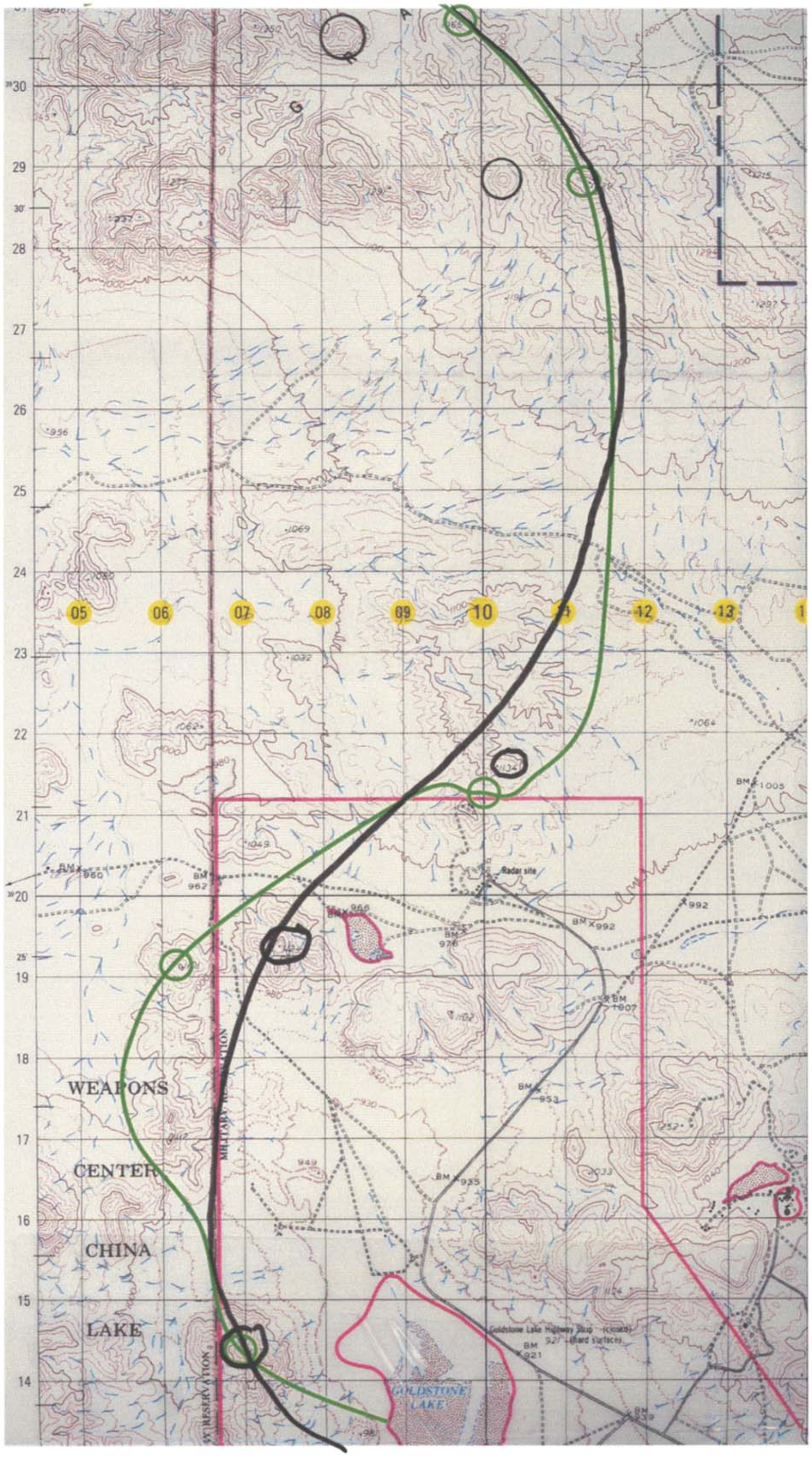


Figure 50. Evaluation Slide P.

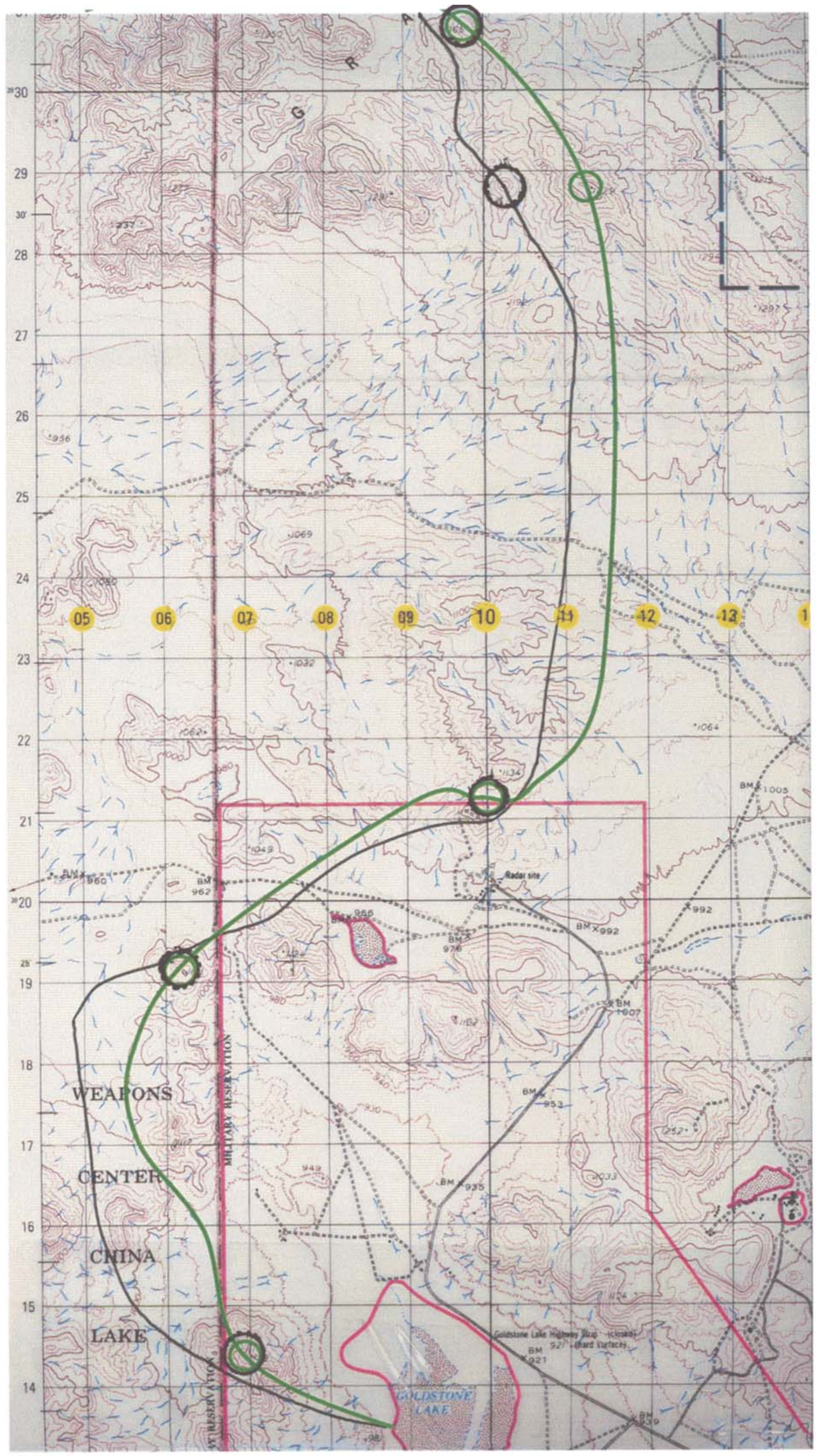


Figure 51. Evaluation Slide Q.

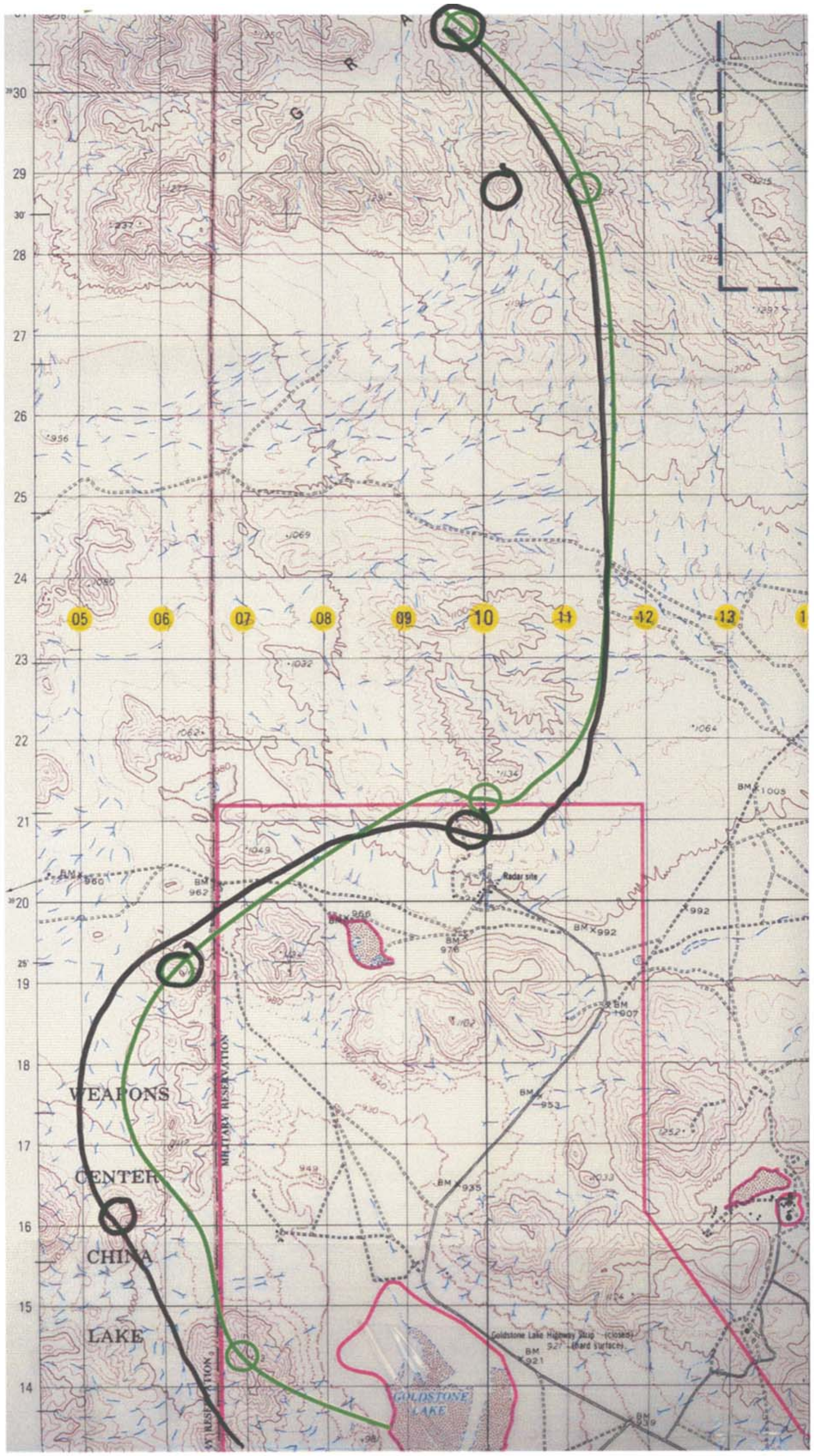


Figure 52. Evaluation Slide R.

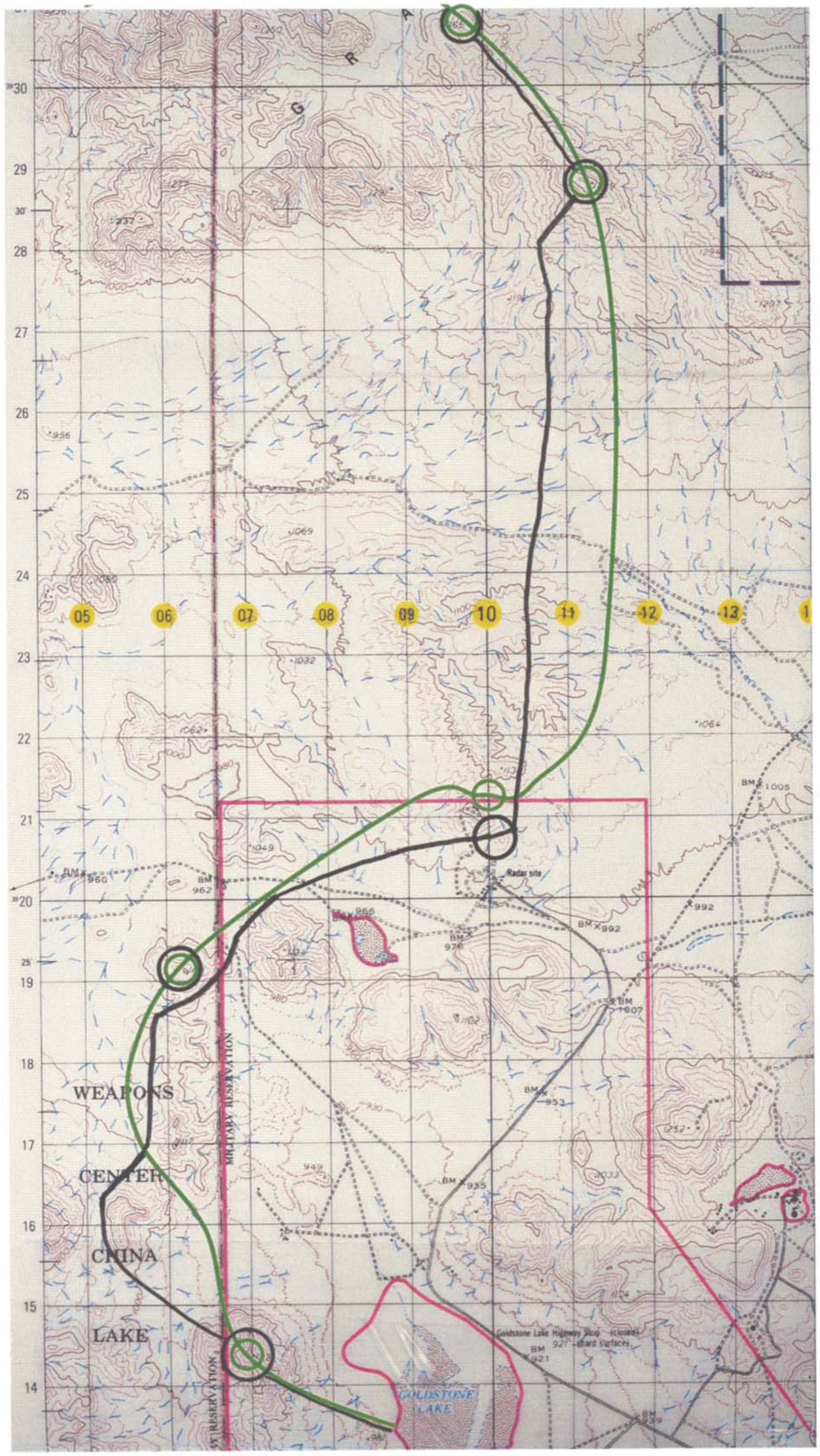


Figure 53. Evaluation Slide T.

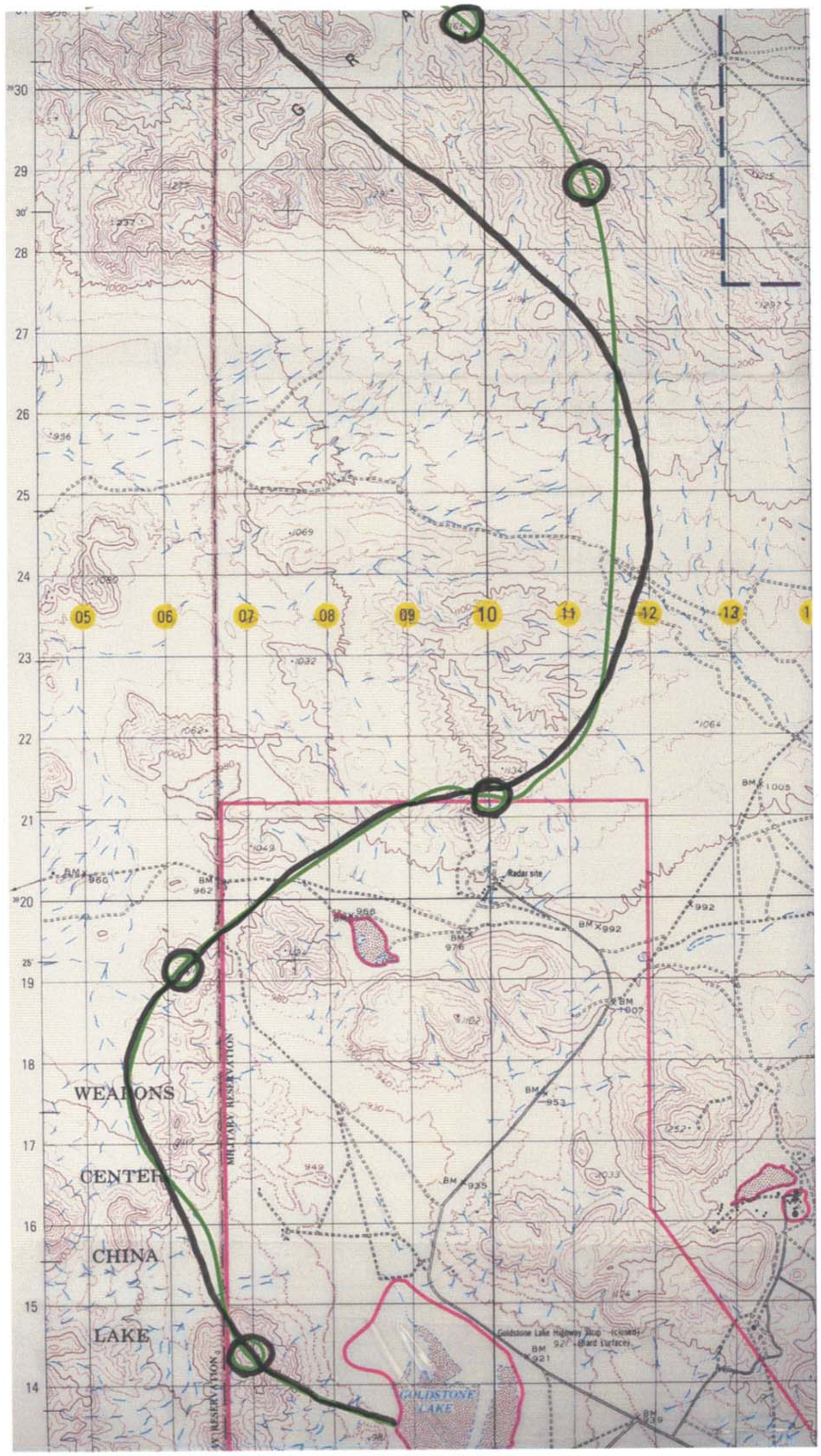


Figure 54. Evaluation Slide U.

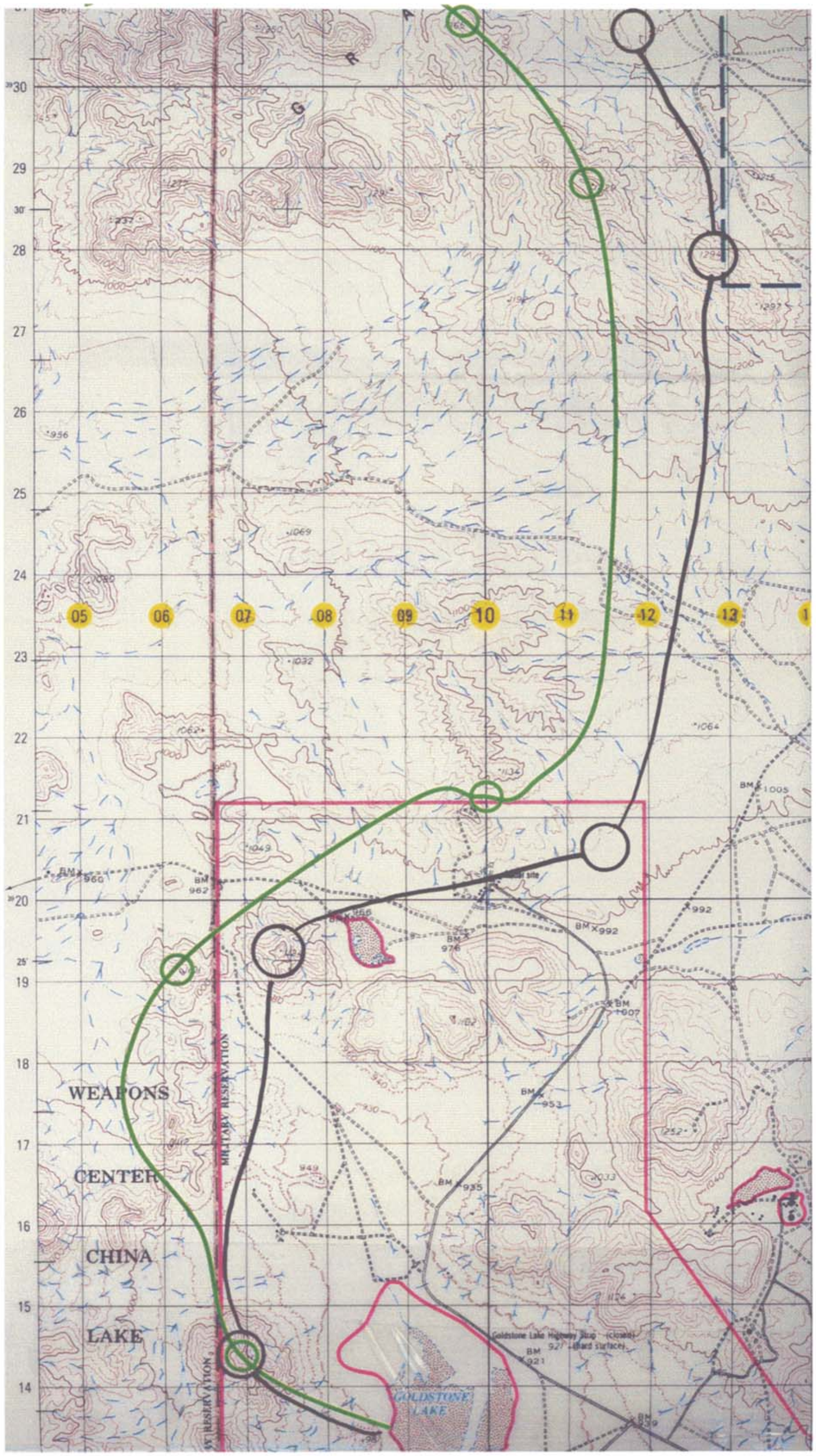


Figure 55. Evaluation Slide W.

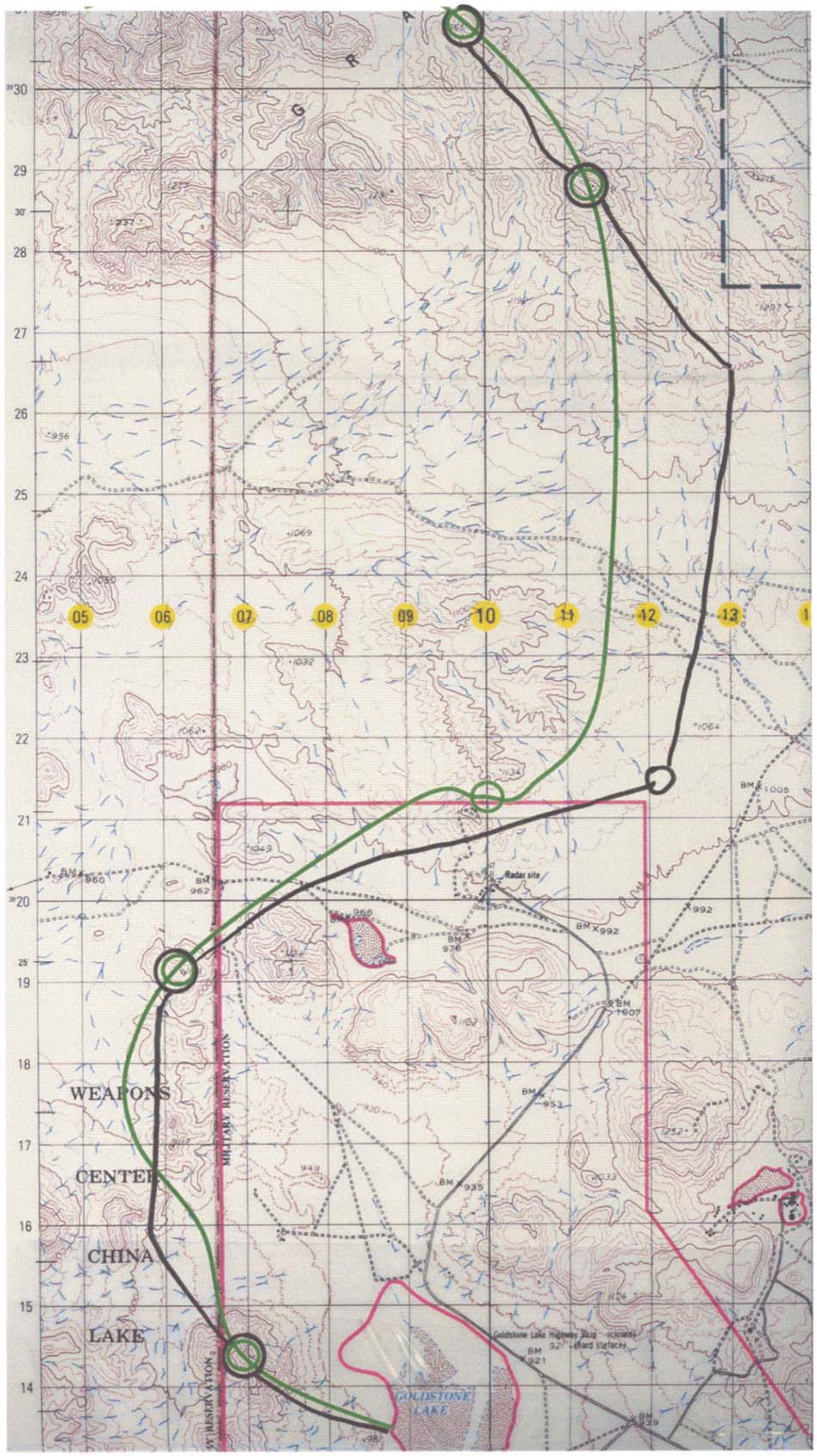


Figure 56. Evaluation Slide Y.

The Goal:
To become sufficiently familiar with the terrain in the Ft Irwin area so as to successfully navigate as much of the route of flight as possible in thirty minutes by providing sound voice commands while using the Chromakeyed Augmented Virtual Environment (ChrAVE) system.

Your Resources:
-2 satellite images
- an image of the Fort Irwin area
- an image concentrated on and depicting the general route of flight

-A 1:50,000 map of the Ft Irwin area (you may write on the map)
-A kneeboard route card (you may write on the route cards)
-A set of map pens
-A collection of rulers, protractors, and stencils
-Two knee boards to use during the flying portion of the experiment
-A clock for timing (you may want to become familiar with its operation)
-One pair of flight gloves required during flight

The Tasks:
Prepare the map: Utilizing the information on the kneeboard route cards and the other resources prepare the 1:50,000 map. You will be relying on this map during the virtual flight portion of the experiment. This will be a non-tactical flight; emphasis is on terrain association and navigation. Prepare your map as though you were unsure whether your flight would be conducted during the day or at night. Take note of key terrain such as checking features, channeling features, and limiting features. When you are comfortable with your preparation inform the proctor.

Maintain awareness of your location: You will be required to plot your direction and position on the map on demand (approximately every two minutes). Place an arrow (↑) to represent your direction; the point of the arrow shall represent your position. The proctor will call out a number for you to place by the arrow. You will be able to refer to the map, instrument panel, the timing clock, and the virtual world during the flight. Remember your view to the left will be limited to the edge of the blue screen. It will be important to associate terrain on the map with the terrain in the virtual world in order to maintain your position. Some (not all) roads are identifiable in the virtual environment. As a rule of thumb, roads and other manmade features clearly identifiable in the satellite imagery are identifiable in the virtual environment. If you are lost, you may instruct the pilot at the controls to orbit in order to regain your orientation. However, your goal is to navigate as much of the route as possible in the time allotted (thirty minutes).

Navigation: Successfully navigate as much of the route of flight as possible in thirty minutes.

Subject Number: ________

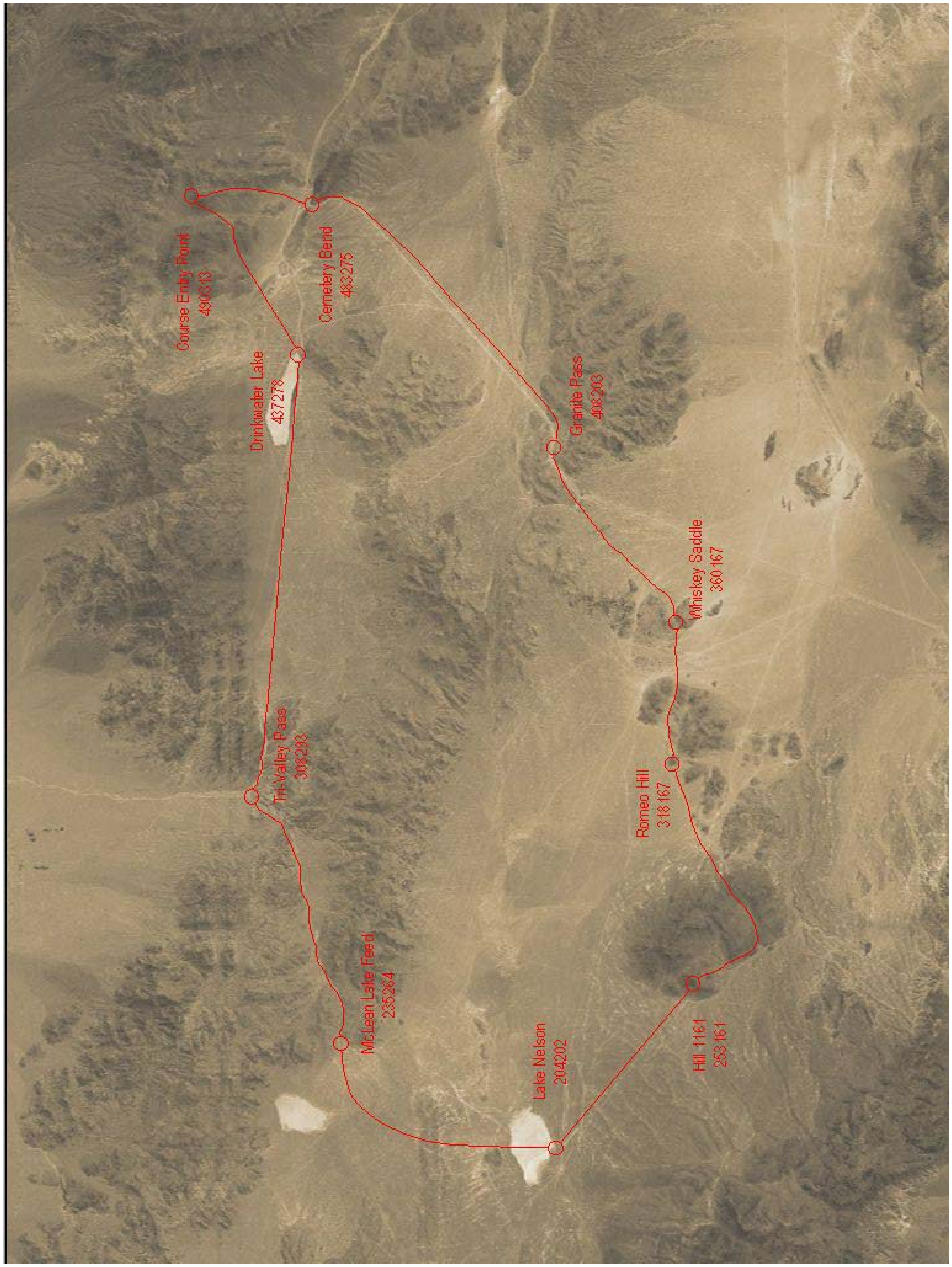


Figure 57. Satellite Image of Fort Irwin Area with intended route of flight overlaid.

Monitor the radios: There will be radio chatter in the Fort Irwin area. Your aircraft's callsign is "Ugly one-two". You are required to answer radio calls only to your aircraft by pressing the button on the cyclic and saying "Ugly one-two, roger." Disregard all other chatter. You may ask the proctor to adjust the volume for you.

Direct the pilot at the controls: During the flight portion of the experiment you will direct the flight of your aircraft by giving appropriate voice commands to the pilot at the controls (the proctor). Directional voice commands are restricted to:
"Left turn" / "Right turn" – These commands start a standard rate turn.
"Easy left turn" / "Easy right turn" – These commands start a half standard rate turn.
"Stop turn" – This command levels the wings.
O'clock position calls – These commands start a standard rate turn followed by and automatic rollout. Turns to 6 o'clock will be right hand turns unless "**Turn left to 6 o'clock**" is requested. A turn to one o'clock means a heading change of 30 degrees, two o'clock means a heading change of 60 degrees, etc.
"**Orbit left**" / "**Orbit right**" – These command should be used only when attempting to reestablish your orientation. These commands will initiate a standard rate turn that maintains altitude (climbs will be initiated only to avoid terrain). Remember a full turn of 360 degrees will take two minutes.
If there is any type of problem, the terms "**Game over**" or "**Pause game**" will pause the game.

Maintain situational awareness: There will be other activity in the Fort Irwin area while you are navigating. Simply call the traffic or activity to the rest of your flight crew when you see it.

Cockpit management: Practice effective cockpit management skills. Remember this trainer will be unfamiliar to you. Plan your map folding adjustments during long straight stretches of flight. Organize necessary resources within your reach.

Flight parameters:

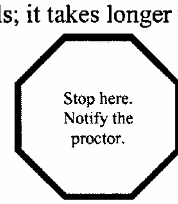
Your aircraft is a 'generic' helicopter.

You will be flying at 90 knots on a windless day. Airspeed equals groundspeed.
-In one minute of flight at 90 knots your aircraft will travel 1.5 NM or 2.778 KM.
-In two minutes of flight at 90 knots your aircraft will travel 3.0 NM or 5.556 KM.

The pilot at the controls will 'visually' maintain about 200 feet AGL. However if orbiting he will maintain 200 feet above the highest object in the orbit path.

Remember to lead your roll out calls; it takes longer to roll out from a standard rate turn than a half standard rate turn.

Do you have any questions?



Subject Number: ________

(proctor use only)
Ensure the subject knows how to use the clock.
Check for history of epilepsy or proneness to simulator sickness

Unhooded Tests:
Eye Test:
Line:____________________ Number correct:________________________

Hand/Eye Coordination Test:
1st throw: Caught / Fumbled / Dropped
2nd throw: Caught / Fumbled / Dropped
3rd throw: Caught / Fumbled / Dropped
4th throw: Caught / Fumbled / Dropped
5th throw: Caught / Fumbled / Dropped
6th throw: Caught / Fumbled / Dropped
7th throw: Caught / Fumbled / Dropped
8th throw: Caught / Fumbled / Dropped
9th throw: Caught / Fumbled / Dropped
10th throw: Caught / Fumbled / Dropped

Color Identification Test:
Blue: Pass / Fail
Red: Pass / Fail
Green: Pass / Fail
Orange: Pass / Fail
Purple: Pass / Fail
Black: Pass / Fail

Dvorine Plates Test:

48	67	38	92	70
95	26	2	74	62

Hooded Tests:
Subject was hooded at time _______________.

Provide instructions on HMD adjustments and a warning on twisting the inertial tracker.

Eye Test:
Line:____________________ Number correct:________________________

Hand/Eye Coordination Test:
1st throw: Caught / Fumbled / Dropped
2nd throw: Caught / Fumbled / Dropped
3rd throw: Caught / Fumbled / Dropped
4th throw: Caught / Fumbled / Dropped
5th throw: Caught / Fumbled / Dropped
6th throw: Caught / Fumbled / Dropped
7th throw: Caught / Fumbled / Dropped
8th throw: Caught / Fumbled / Dropped
9th throw: Caught / Fumbled / Dropped
10th throw: Caught / Fumbled / Dropped

Color Identification Test:
Blue: Pass / Fail
Red: Pass / Fail
Green: Pass / Fail
Orange: Pass / Fail
Purple: Pass / Fail
Black: Pass / Fail

Dvorine Plates Test:

48	67	38	92	70
95	26	2	74	62

(proctor use only)

Flight Portion:

Set up:

1. Set-up ChrAVE.
2. Prep sound file to minute ten.
3. Start Vega Desert Trap scenario on ChrAVE cart.
4. Start Vega Instrument Panel on the SGI.
5. Start Top View on the desktop PC.
6. Set stopwatch to 3 minutes.
7. Configure Desert Trap scenario:
   a. Turn off flight paths (buttons 'Z', 'X', and 'C')
   b. Press 'A' to place subject at the alternate practice position.
   c. Ensure the compass matches the users answer to question 16. Magnetic / Grid
8. When the subject is ready press 'P' to toggle off pause.
9. Start sound file.
10. Have subject start the stopwatch to begin his prep-time.
11. Prep sound file to beginning.
12. Press "R" to place the subject at the start position.
13. When the subject is ready press 'P' to toggle off pause.
14. Start sound file.

Radio Calls:

1st call:	○Correctly heard & acknowledged ○Not acknowledged ○Acknowledged call for others
2nd call:	○Correctly heard & acknowledged ○Not acknowledged ○Acknowledged call for others
3rd call:	○Correctly heard & acknowledged ○Not acknowledged ○Acknowledged call for others
4th call:	○Correctly heard & acknowledged ○Not acknowledged ○Acknowledged call for others
5th call:	○Correctly heard & acknowledged ○Not acknowledged ○Acknowledged call for others
6th call:	○Correctly heard & acknowledged ○Not acknowledged ○Acknowledged call for others
7th call:	○Correctly heard & acknowledged ○Not acknowledged ○Acknowledged call for others
8th call:	○Correctly heard & acknowledged ○Not acknowledged ○Acknowledged call for others
9th call:	○Correctly heard & acknowledged ○Not acknowledged ○Acknowledged call for others
10th call:	○Correctly heard & acknowledged ○Not acknowledged ○Acknowledged call for others

Other comments:

Head movements: Subtle / Moderate / Rapid

____

Subject Number: ________

Hooded Tests:

Eye Test:

Line:____________________ Number correct:________________________

Hand/Eye Coordination Test:		Color Identification Test:	
1st throw:	Caught / Fumbled / Dropped	Blue:	Pass / Fail
2nd throw:	Caught / Fumbled / Dropped	Red:	Pass / Fail
3rd throw:	Caught / Fumbled / Dropped	Green:	Pass / Fail
4th throw:	Caught / Fumbled / Dropped	Orange:	Pass / Fail
5th throw:	Caught / Fumbled / Dropped	Purple:	Pass / Fail
6th throw:	Caught / Fumbled / Dropped	Black:	Pass / Fail
7th throw:	Caught / Fumbled / Dropped		
8th throw:	Caught / Fumbled / Dropped	Dvorine Plates Test:	
9th throw:	Caught / Fumbled / Dropped	48 67 38 92 70	
10th throw:	Caught / Fumbled / Dropped	95 26 2 74 62	

Unhooded Tests:

Subject was unhooded at time_______________.

Total HMD exposure: _____________.

Eye Test:

Line:____________________ Number correct:________________________

Hand/Eye Coordination Test:		Color Identification Test:	
1st throw:	Caught / Fumbled / Dropped	Blue:	Pass / Fail
2nd throw:	Caught / Fumbled / Dropped	Red:	Pass / Fail
3rd throw:	Caught / Fumbled / Dropped	Green:	Pass / Fail
4th throw:	Caught / Fumbled / Dropped	Orange:	Pass / Fail
5th throw:	Caught / Fumbled / Dropped	Purple:	Pass / Fail
6th throw:	Caught / Fumbled / Dropped	Black:	Pass / Fail
7th throw:	Caught / Fumbled / Dropped		
8th throw:	Caught / Fumbled / Dropped	Dvorine Plates Test:	
9th throw:	Caught / Fumbled / Dropped	48 67 38 92 70	
10th throw:	Caught / Fumbled / Dropped	95 26 2 74 62	

Ask the subject if he/she had to adjust to the real world when the HMD came off?

Yes / No

 Subject Number: ________

Post-flight Questions:

ChrAVE Activity

26. Did you observe the enemy armor unit? Yes / No

    If yes:
    What color smoke was coming from the enemy armor unit? ____________________

    How many tanks did you observe? ○Zero ○One ○Two ○Three ○Four

    How many personnel carriers did you observe? ○Zero ○One ○Two ○Three ○Four

27. Did you observe the downed aircraft? Yes / No

    If yes:
    What color smoke was coming from the aircraft? ____________________________

    How many aircrew did you observe? ○Zero ○One ○Two ○Three ○Four

28. Did you observe the small town in the vicinity of Nelson Airfield? Yes / No

    If yes:
    Did you could observe any vehicle traffic in the small town? Yes / No

    Did you could observe the church in the small town? Yes / No

29. Did you observe any evidence of close air support (CAS) traffic? Yes / No

    If yes:
    What did you observe? ○Harrier(s) ○Contrails from a Jet ○Canopy reflection / flash

30. Did you observe any other aircraft? Yes / No

    If yes:
    What aircraft did you see? (Check all that apply)
    ○UH-1 ○CH-46 ○CH-53 ○V-22 ○Don't know

ChrAVE Performance

(Select the appropriate response following each statement.)

31. Navigating in the ChrAVE resembled the actual task of navigation?
    ○Strongly agree ○Agree ○Neither agree nor disagree ○Disagree ○Strongly disagree

32. The voice commands I gave in the ChrAVE resembled actual voice commands used in terrain flight navigation?
    ○Strongly agree ○Agree ○Neither agree nor disagree ○Disagree ○Strongly disagree

Subject Number: ________

33. The ChrAVE performs as well as visual simulators I have used in the past with regard to terrain flight navigation?
   ○Strongly agree ○Agree ○Neither agree nor disagree ○Disagree ○Strongly disagree

34. The ChrAVE is more valuable as a tool than desktop simulators I have used in the past with regard to terrain flight navigation?
   ○Strongly agree ○Agree ○Neither agree nor disagree ○Disagree ○Strongly disagree

35. The ChrAVE required me to use cockpit management skills similar to cockpit management skills I use in actual aircraft?
   ○Strongly agree ○Agree ○Neither agree nor disagree ○Disagree ○Strongly disagree

36. If the ChrAVE was able to transform aircraft aboard underway ships into the navigational tool I saw today, I would be likely to use it?
   ○Strongly agree ○Agree ○Neither agree nor disagree ○Disagree ○Strongly disagree

37. Viewing the map through the HMD was acceptable.
   ○Strongly agree ○Agree ○Neither agree nor disagree ○Disagree ○Strongly disagree

38. Viewing the kneeboard card on the kneeboard through the HMD was acceptable.
   ○Strongly agree ○Agree ○Neither agree nor disagree ○Disagree ○Strongly disagree

39. Viewing the instrument panel through the HMD was acceptable.
   ○Strongly agree ○Agree ○Neither agree nor disagree ○Disagree ○Strongly disagree

40. The terrain appeared realistically in size and dimension.
   ○Strongly agree ○Agree ○Neither agree nor disagree ○Disagree ○Strongly disagree

ChrAVE Aftereffects

41. The ChrAVE made me feel queasy / nauseous.
   ○Strongly agree ○Agree ○Neither agree nor disagree ○Disagree ○Strongly disagree

42. The ChrAVE is disorienting because it is a motionless platform.
   ○Strongly agree ○Agree ○Neither agree nor disagree ○Disagree ○Strongly disagree

43. The ChrAVE provides a 60-degree field of view (FOV). If a wider field of view were available it would be more beneficial.
   ○Strongly agree ○Agree ○Neither agree nor disagree ○Disagree ○Strongly disagree

44. If a wider field of view were available it would induce less discomfort/nausea.
   ○Strongly agree ○Agree ○Neither agree nor disagree ○Disagree ○Strongly disagree

45. I would want a wider FOV even if the resulting headgear were heavier/bulkier?
   ○Strongly agree ○Agree ○Neither agree nor disagree ○Disagree ○Strongly disagree

Experiment Tasks

46. The tasks were realistic.

    Preparing the map
    ❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree

    Maintaining awareness of your location
    ❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree

    Terrain association
    ❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree

    Navigation
    ❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree

    Monitoring radio calls
    ❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree

    Directing the pilot at the controls / Voice commands
    ❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree

    Maintaining situational awareness / seeing other aircraft or activity
    ❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree

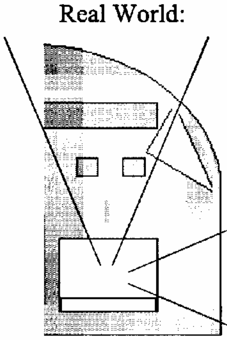
    Cockpit management skills
    ❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree

47. The workload in the ChrAVE was the same as it is in real world low-level helicopter navigation.
    a. ❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree
    b. ❍Less ❍Same ❍More

48. The stress level in the ChrAVE was the same as it is in real world low-level helicopter navigation.
    a. ❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree
    b. ❍Less ❍Same ❍More

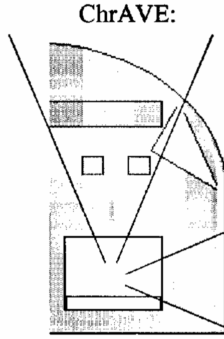
49. Enter the percent of time your gaze is/was directed in each of the following glassed regions.

Real World:



Front ______%
Oblique ______%
Chin Bubble ______%
Right ______%

ChrAVE:



Front ______%
Oblique ______%
Chin Bubble ______%
Right ______%

50. What suggestions for improvements of the ChrAVE do you have? Please add any other statements you may have concerning this experiment. (If you have a comment on a specific question please provide the question number.):

Thank you for your participation.

12 Subject Number: ________

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APPENDIX C. SUBJECT FLIGHT DATA

		Check Points												
		1	2	3	4	5	6	7	8	9	10	11		
	Subject	Course Entry Point	Cemetery Bend	Granite Pass	Whiskey Saddle	Romeo Hill	Hill 1161	Nelson Lake	McLean Lake Feed	Tri-valley Pass	Drinkwater Lake	Course Entry Point	Average Distance **	Proximity Rank
Min Distance from Flown Path to Checkpoint (Meters)	001	0.0	288.6	528.9	473.3	187.7	183.1	71.0	462.6	969.4	214.7	779.3	375	2
	002	0.0	265.1	511.9	71.6	122.1	1008.2	389.3	250.6	598.4	230.3	146.6	383	3
	003	0.0	271.0	311.2	1399.3	357.8	882.3	33.6	357.8	4,665.4	3,307.1	3220.2	1287	14
	004	0.0	1089.1	183.4	157.9	1,022.6	192.6	144.9	419.1	824.8	4,985.1	5059.5	1002	13
	005	0.0	610.0	131.6	1306.7	1,631.8	230.7	252.1	1155.8	501.3	159.1	4186.5	664	10
	006	0.0	418.4	36.7	395.4	462.6	941.0	5,345.5	3421.7	2,031.9	275.5	2250.5	1481	15
	007	0.0	421.6	504.7	3084.1	1,092.4	412.9	118.6	208.1	534.4	31.3	1723.9	712	12
	008	0.0	394.9	1,600.1	639.8	1,751.7	192.0	349.4	572.5	539.8	254.3	32.2	699	11
	009	0.0	949.2	204.9	297.5	2,119.6	167.2	211.0	397.4	733.7	251.4	539.5	592	8
	010	0.0	461.4	70.9	23.8	309.9	261.9	30.3	242.8	563.9	130.0	456.3	233	1
	011	0.0	478.9	59.7	245.0	1,464.7	211.0	209.5	674.1	1,101.9	476.1	283.1	547	5
	012	0.0	472.1	240.5	60.7	1,653.0	604.2	253.2	726.4	694.1	75.1	1363.4	531	4
	013	0.0	466.0	204.2	129.4	704.2	1598.9	639.9	670.1	334.3	1,122.6	476.7	652	9
	014	0.0	711.9	296.7	403.9	2,082.7	280.9	77.3	380.5	835.3	120.1	104.2	577	7
	015	0.0	460.0	53.2	380.0	1,218.9	362.6	693.7	726.2	755.5	538.5	1184.7	577	6
Average Distance-->		0.0	517.2	329.3	604.6	1,078.8	502.0	587.9	711.0	1,045.6	811.4	1,453.8	688	
Difficulty Ranking-->		*	7	9	5	1	8	6	4	2	3	*		

* Note checkpoints 1 and 15 were not factored into the checkpoint difficulty ranking because all subjects began at checkpoint 1 and not all subjects were able to complete the route, thereby never attempting to navigate to checkpoint 15.

** Note only checkpoints 2 and 14 were factored into this average because all subjects began at checkpoint 1 and not all subjects were able to complete the route, thereby never attempting to navigate to checkpoint 15 from the previous checkpoint.

Table 3. Subject pool's proximity to each checkpoint.

Subject001's Location, Direction, & Proximity Results

		Subject's Map Plots			Subject's VE Positions			Difference	
	Time	Easting	Northing	Heading (Grid)	Easting	Northing	Heading (Grid)	Distance (Meters)	Heading (Deg)
1	03:02	458.3	232.8	224.5	460.2	236.3	227.3	399.5	2.8
2	05:10	407.7	199.8	257.5	412.4	199.1	245.8	479.8	11.7
3	07:00	359.0	172.8	250.0	373.0	165.6	254.7	1,575.8	4.7
4	08:59	318.5	168.5	268.5	321.6	165.0	272.3	465.8	3.8
5	10:58	255.0	156.7	312.5	269.0	153.9	299.9	1,430.8	12.6
6	12:57	210.4	194.5	339.5	223.1	185.4	312.3	1,561.7	27.2
7	14:56	209.1	217.5	040.5	208.9	216.6	032.6	90.3	7.9
8	16:57	234.5	264.7	040.0	230.8	265.9	019.3	392.5	20.7
9	18:57	281.2	278.0	086.0	281.3	277.3	077.8	68.8	8.2
10	20:57	329.5	289.2	095.0	336.1	284.6	086.8	801.8	8.2
11	22:55	405.8	282.1	100.0	388.7	286.2	086.0	1,755.2	14.0
12	24:56	440.0	278.3	090.0	442.3	278.7	098.4	237.8	8.4
13	26:55	474.6	314.9	090.0	487.9	305.5	100.5	1,632.5	10.5
14	28:56	489.0	314.5	127.5	534.3	296.9	188.1	4,856.4	60.6
15									
							Averages-->	1,124.9	14.4

*Blanks indicate subject did not plot

	Check Points			
	Check Point Name	Easting	Northing	Min Distance from Flown Path to Checkpoint (Meters)
1	Course Entry Point	490.0	313.0	0.0
2	Cemetery Bend	483.0	275.0	288.6
3	Granite Pass	408.0	203.0	528.9
4	Whiskey Saddle	360.0	167.0	473.3
5	Romeo Hill	318.0	167.0	187.7
6	Hill 1161	253.0	161.0	183.1
7	Nelson Lake	204.0	202.0	71.0
8	McLean Lake Feed	235.0	264.0	462.6
9	Tri-valley Pass	308.0	293.0	969.4
10	Drinkwater Lake	437.0	278.0	214.7
11	Course Entry Point	490.0	313.0	779.3
			Average-->	378.1

Table 4. Subject001’s Location, Direction, & Proximity Results.

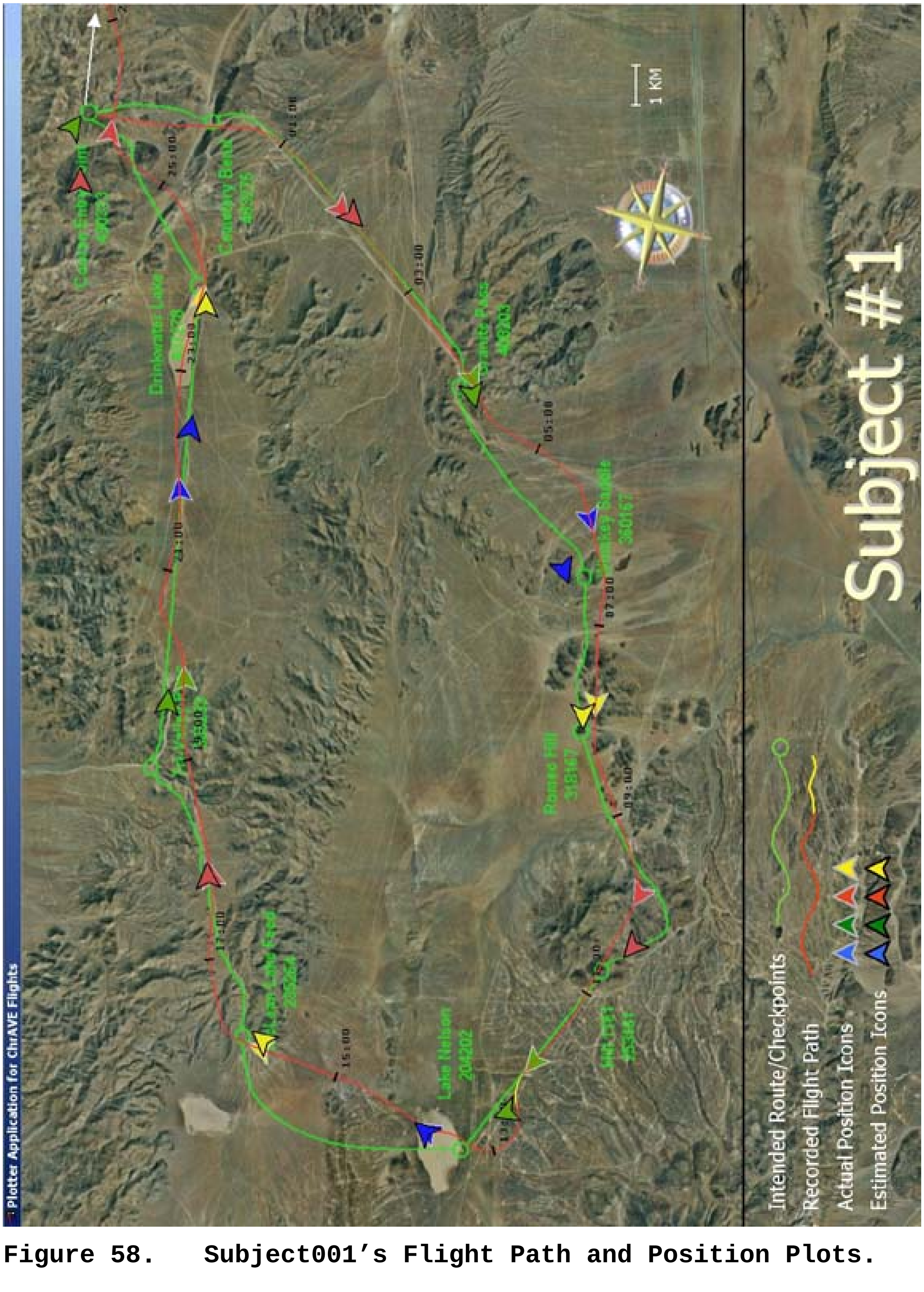

Figure 58. Subject001's Flight Path and Position Plots.

Subject002's Location, Direction, & Proximity Results

		Subject's Map Plots			Subject's VE Positions			Difference	
	Time	Easting	Northing	Heading (Grid)	Easting	Northing	Heading (Grid)	Distance (Meters)	Heading (Deg)
1	04:15	456.0	239.5	231.0	456.3	235.3	214.8	421.5	16.2
2	06:16	416.3	194.9	228.0	412.3	199.5	240.4	614.5	12.4
3	08:13	362.2	166.5	270.0	368.0	169.4	237.3	647.5	32.7
4	10:12	314.9	165.8	258.5	313.9	167.7	260.6	212.7	2.1
5	12:09	253.1	154.6	000.5	267.7	144.9	276.0	1,750.0	84.5
6	14:13	206.2	195.5	357.5	231.0	179.1	324.4	2,975.0	33.1
7	16:07	204.9	227.6	002.5	206.2	219.2	014.3	844.8	11.8
8	18:06	232.4	258.5	029.0	237.0	262.4	043.7	603.1	14.7
9	20:05	298.2	288.0	070.0	287.7	282.7	078.3	1,181.2	8.3
10	22:27	337.8	293.5	101.5	353.3	286.5	105.5	1,697.3	4.0
11	24:11	400.1	278.8	104.5	400.1	280.6	095.3	182.4	9.2
12	26:05	445.2	281.7	065.5	451.4	286.6	057.0	787.7	8.5
13	27:60	495.2	314.5	084.5	493.8	320.7	039.1	633.3	45.4
14									
15									
							Averages-->	965.5	21.7

*Blanks indicate subject did not plot

	Check Points			
	Check Point Name	Easting	Northing	Min Distance from Flown Path to Checkpoint (Meters)
1	Course Entry Point	490.0	313.0	0.0
2	Cemetery Bend	483.0	275.0	265.1
3	Granite Pass	408.0	203.0	511.9
4	Whiskey Saddle	360.0	167.0	71.6
5	Romeo Hill	318.0	167.0	122.1
6	Hill 1161	253.0	161.0	1,008.2
7	Nelson Lake	204.0	202.0	389.3
8	McLean Lake Feed	235.0	264.0	250.6
9	Tri-valley Pass	308.0	293.0	598.4
10	Drinkwater Lake	437.0	278.0	230.3
11	Course Entry Point	490.0	313.0	146.6
			Average-->	326.7

Table 5. Subject002’s Location, Direction, & Proximity Results.

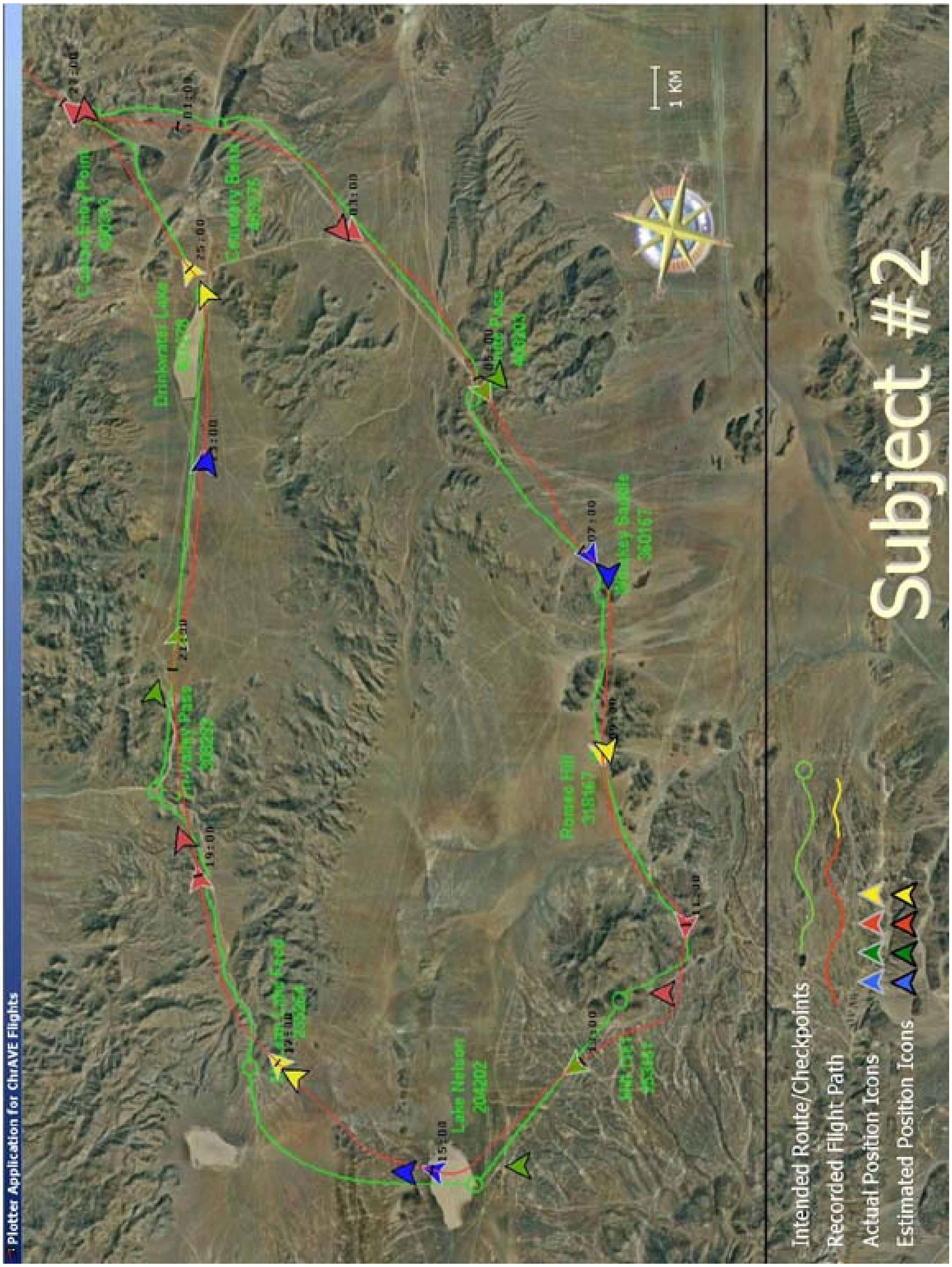

Figure 59. Subject002’s Flight Path and Position Plots.

Subject003's Location, Direction, & Proximity Results

		Subject's Map Plots			Subject's VE Positions			Difference	
	Time	Easting	Northing	Heading (Grid)	Easting	Northing	Heading (Grid)	Distance (Meters)	Heading (Deg)
1	06:10								
2	06:12	412.5	201.5	264.0	418.1	204.5	243.9	637.7	20.1
3	08:46	374.7	167.5	200.0	394.9	171.8	197.9	2,060.6	2.2
4	09:20								
5	09:21								
6	09:22								
7	09:23								
8	18:01	302.0	165.5	272.0	306.0	174.8	277.0	1,010.6	5.0
9	20:02	258.0	155.0	320.0	265.5	138.1	266.7	1,853.3	53.3
10	21:60	215.1	187.5	342.0	226.8	178.2	319.7	1,494.7	22.3
11	24:02	204.1	225.5	360.0	201.8	220.9	016.6	512.5	16.6
12	26:02	224.0	266.0	050.0	243.2	245.8	057.1	2,790.3	7.1
13	28:05	224.7	256.0	215.0	246.6	249.1	095.9	2,291.9	119.1
14	30:01	239.5	247.1	040.0	300.3	244.0	078.9	6,087.8	38.9
15	31:55	419.0	261.5	048.0	352.7	251.8	092.5	6,697.0	44.5
							Averages-->	2,543.6	32.9

*Blanks indicate subject did not plot

	Check Points			
	Check Point Name	Easting	Northing	Min Distance from Flown Path to Checkpoint (Meters)
1	Course Entry Point	490.0	313.0	0.0
2	Cemetery Bend	483.0	275.0	271.0
3	Granite Pass	408.0	203.0	311.2
4	Whiskey Saddle	360.0	167.0	1,399.3
5	Romeo Hill	318.0	167.0	357.8
6	Hill 1161	253.0	161.0	882.3
7	Nelson Lake	204.0	202.0	33.6
8	McLean Lake Feed	235.0	264.0	357.8
9	Tri-valley Pass	308.0	293.0	4,665.4
10	Drinkwater Lake	437.0	278.0	3,307.1
11	Course Entry Point	490.0	313.0	3,220.2
			Average-->	1,346.0

Table 6. Subject003's Location, Direction, & Proximity Results.

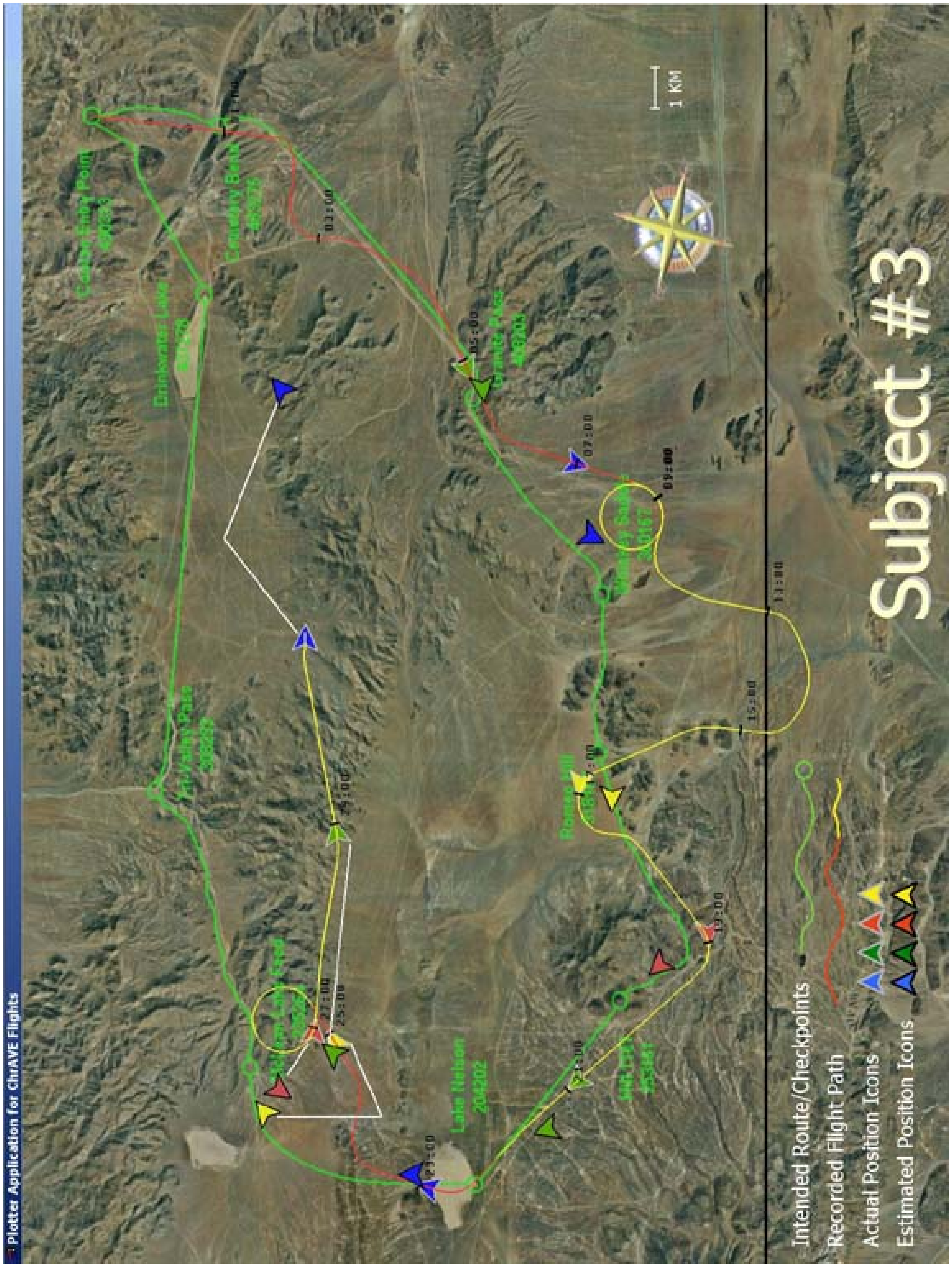

Figure 60. Subject003’s Flight Path and Position Plots.

Subject004's Location, Direction, & Proximity Results

		Subject's Map Plots			Subject's VE Positions			Difference	
	Time	Easting	Northing	Heading (Grid)	Easting	Northing	Heading (Grid)	Distance (Meters)	Heading (Deg)
1	02:44	487.0	268.0	158.0	486.0	260.8	201.0	726.2	43.0
2	04:45	466.8	237.9	246.0	454.3	218.1	232.4	2,339.9	13.6
3	06:44	400.1	200.3	269.0	404.1	197.0	225.3	519.6	43.7
4	08:44	349.5	164.6	284.0	357.6	164.1	245.1	809.6	38.9
5	10:42	306.8	167.5	231.0	301.1	153.1	218.9	1,550.5	12.1
6	12:44	285.1	155.0	242.5	256.5	128.4	268.0	3,907.7	25.5
7	14:40	286.9	168.2	172.3	225.9	151.8	023.6	6,319.8	148.7
8	16:40	284.9	162.6	245.0	259.2	140.4	194.2	3,396.0	50.8
9	18:52	232.7	152.5	332.0	224.1	136.3	348.1	1,839.4	16.1
10	20:39	207.3	197.0	325.0	212.2	180.9	330.7	1,678.6	5.7
11	22:38	202.5	224.5	360.0	208.9	227.3	359.5	698.3	0.5
12	24:39	242.7	265.6	086.5	238.2	269.5	089.2	598.8	2.7
13	26:38	280.0	273.7	077.0	290.1	280.2	076.4	1,200.6	0.6
14	28:40	306.0	285.7	018.0	341.9	297.1	051.8	3,765.1	33.8
15	30:40	327.9	292.1	096.0	394.0	303.2	082.2	6,698.1	13.8
							Averages-->	2,403.2	30.0

*Blanks indicate subject did not plot

	Check Points			
	Check Point Name	Easting	Northing	Min Distance from Flown Path to Checkpoint (Meters)
1	Course Entry Point	490.0	313.0	0.0
2	Cemetery Bend	483.0	275.0	1,089.1
3	Granite Pass	408.0	203.0	183.4
4	Whiskey Saddle	360.0	167.0	157.9
5	Romeo Hill	318.0	167.0	1,022.6
6	Hill 1161	253.0	161.0	192.6
7	Nelson Lake	204.0	202.0	144.9
8	McLean Lake Feed	235.0	264.0	419.1
9	Tri-valley Pass	308.0	293.0	824.8
10	Drinkwater Lake	437.0	278.0	4,985.1
11	Course Entry Point	490.0	313.0	5,059.5
			Average-->	1,279.9

Table 7. Subject004’s Location, Direction, & Proximity Results.

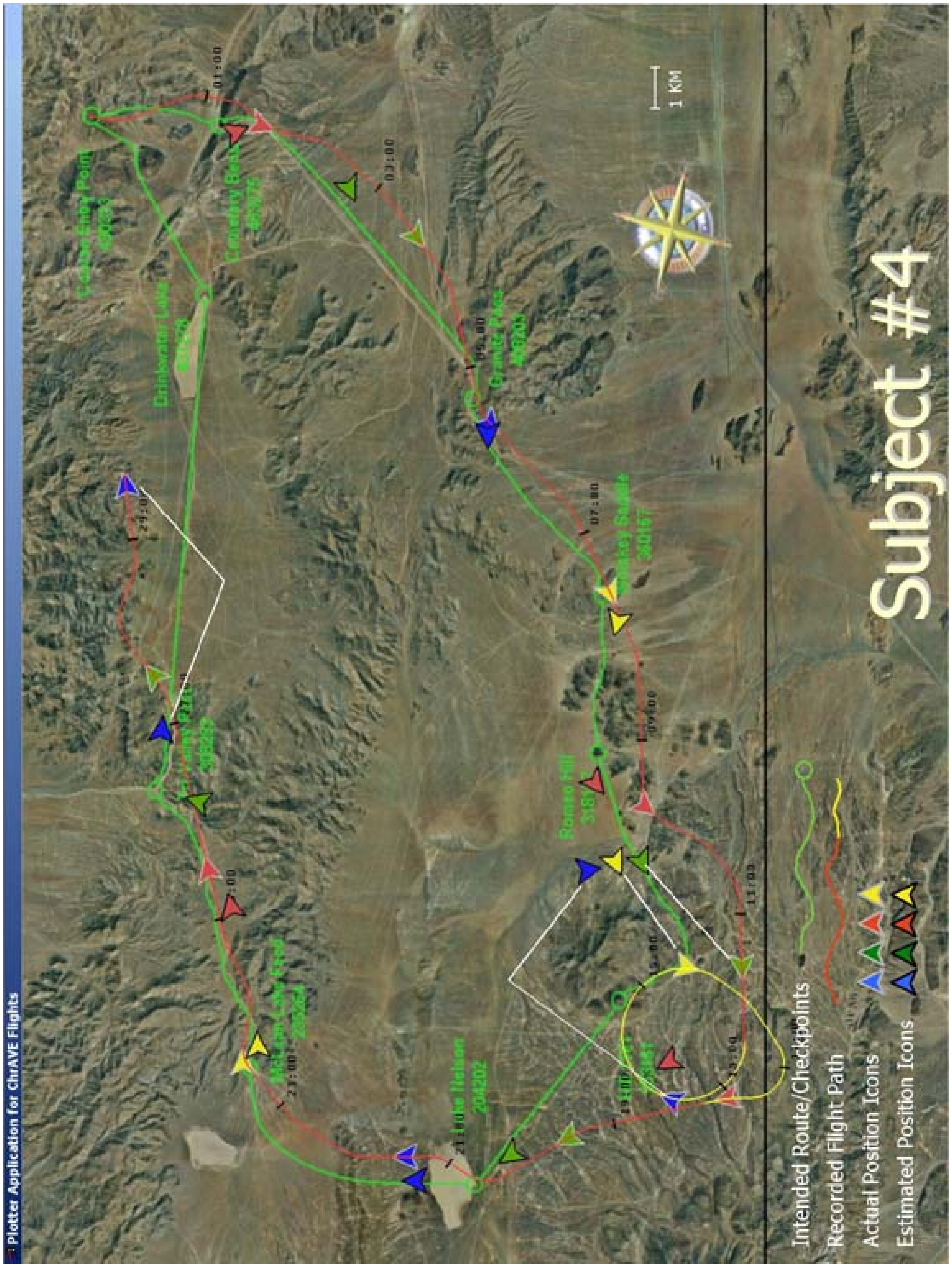

Figure 61. Subject004’s Flight Path and Position Plots.

Subject005's Location, Direction, & Proximity Results

		Subject's Map Plots			Subject's VE Positions			Difference	
	Time	Easting	Northing	Heading (Grid)	Easting	Northing	Heading (Grid)	Distance (Meters)	Heading (Deg)
1	03:02	460.9	246.2	238.0	464.7	243.6	216.2	455.1	21.8
2	05:01	420.0	195.0	254.0	429.4	204.7	259.1	1,348.6	5.1
3	07:01								
4	09:01	391.1	189.6	220.0	399.9	201.7	248.1	1,501.3	28.1
5	10:59	354.9	160.7	288.0	374.1	159.4	210.5	1,923.0	77.5
6	13:01	309.8	170.2	259.0	338.3	175.4	336.4	2,898.8	77.4
7	14:60	280.0	163.7	251.0	293.6	179.9	224.3	2,110.3	26.7
8	16:58	238.4	167.5	336.5	250.4	159.1	280.8	1,465.3	55.7
9	18:59	213.7	189.5	339.0	211.2	185.2	331.2	499.5	7.8
10	20:57	207.8	232.2	002.0	195.5	229.5	340.5	1,261.1	21.5
11	22:56	223.4	256.8	077.0	214.4	266.0	058.4	1,287.5	18.6
12	24:56	256.5	272.2	081.0	268.5	276.2	081.0	1,263.5	0.0
13	27:01								
14	28:55	405.0	273.7	098.0	379.7	291.1	102.3	3,072.1	4.3
15	30:58	438.0	272.6	100.0	438.1	279.5	096.2	687.8	3.8
							Averages-->	1,521.1	26.8

*Blanks indicate subject did not plot

	Check Points			
	Check Point Name	Easting	Northing	Min Distance from Flown Path to Checkpoint (Meters)
1	Course Entry Point	490.0	313.0	0.0
2	Cemetery Bend	483.0	275.0	610.0
3	Granite Pass	408.0	203.0	131.6
4	Whiskey Saddle	360.0	167.0	1,306.7
5	Romeo Hill	318.0	167.0	1,631.8
6	Hill 1161	253.0	161.0	230.7
7	Nelson Lake	204.0	202.0	252.1
8	McLean Lake Feed	235.0	264.0	1,155.8
9	Tri-valley Pass	308.0	293.0	501.3
10	Drinkwater Lake	437.0	278.0	159.1
11	Course Entry Point	490.0	313.0	4,186.5
			Average-->	924.1

Table 8. Subject005’s Location, Direction, & Proximity Results.

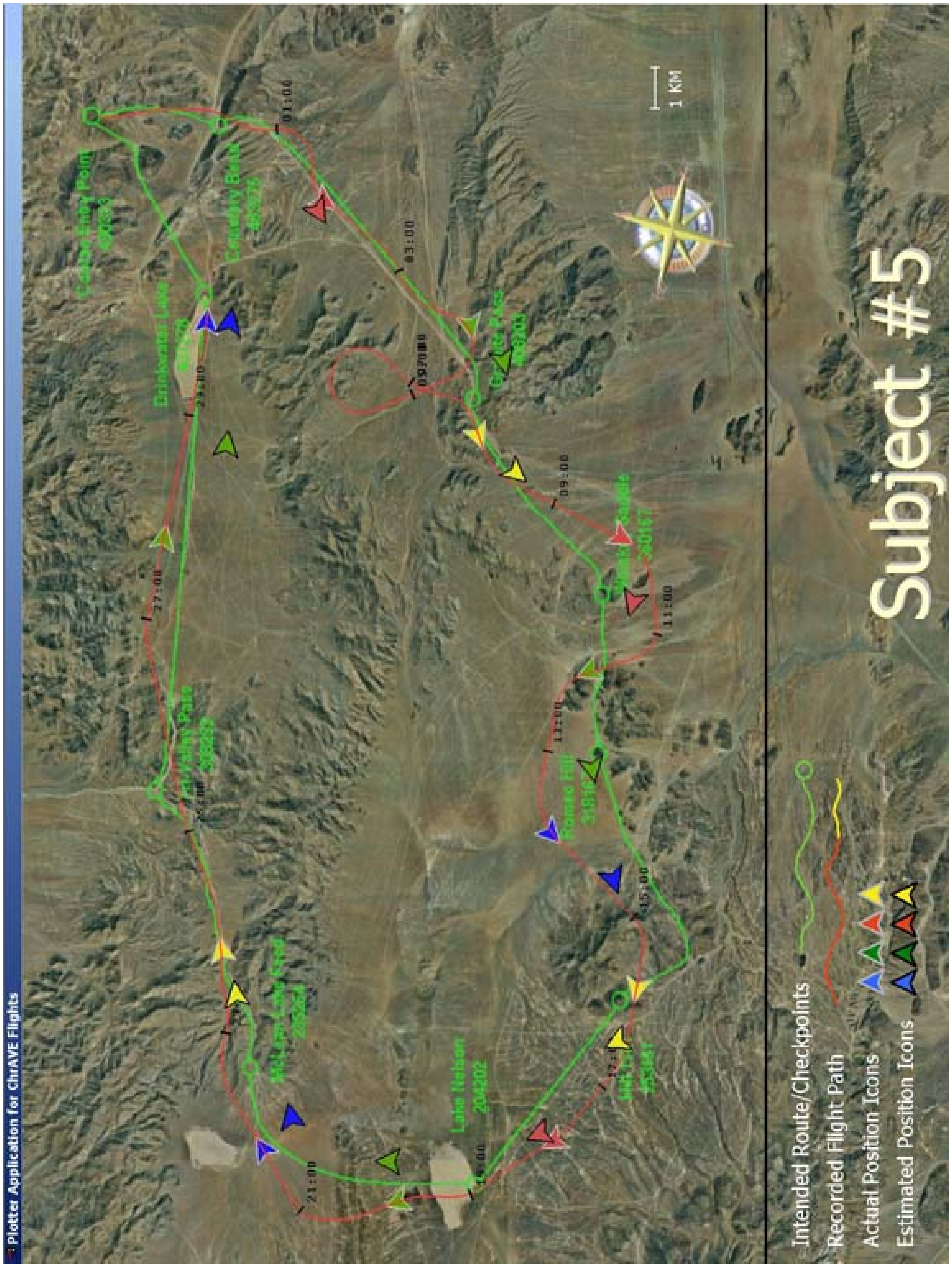

Figure 62. Subject005's Flight Path and Position Plots.

Subject006's Location, Direction, & Proximity Results

		Subject's Map Plots			Subject's VE Positions			Difference	
	Time	Easting	Northing	Heading (Grid)	Easting	Northing	Heading (Grid)	Distance (Meters)	Heading (Deg)
1	03:00								
2	04:58	443.1	210.5	150.6	457.0	230.9	230.9	2,470.5	80.3
3	06:58	403.1	195.1	267.5	413.9	208.0	251.9	1,685.3	15.6
4	08:53	363.0	172.1	232.0	370.8	175.2	215.9	844.0	16.1
5	10:51	294.8	185.5	303.0	328.3	157.2	303.7	4,384.1	0.7
6	12:50	246.2	150.0	330.0	292.2	133.4	257.3	4,888.6	72.7
7	14:50	210.3	159.0	344.0	263.2	162.4	328.0	5,300.6	16.0
8	16:51	232.5	212.3	352.0	281.2	192.7	029.2	5,255.3	37.2
9	18:51	246.7	251.7	342.0	287.9	241.8	325.3	4,236.8	16.7
10	20:52	377.0	291.9	092.5	282.9	280.3	109.4	9,478.9	16.9
11	22:48	426.8	272.5	016.2	328.3	266.7	040.8	9,862.4	24.6
12	24:51	450.0	277.5	041.0	377.1	290.6	081.8	7,403.1	40.8
13	26:50	430.0	281.5	118.0	427.7	286.7	128.7	571.8	10.7
14	28:50	462.0	297.8	054.0	479.5	285.2	090.5	2,155.0	36.5
15	30:50	478.2	327.0	359.0	527.0	298.2	367.4	5,669.5	8.4
							Averages-->	4,586.1	28.1

*Blanks indicate subject did not plot

	Check Points			
	Check Point Name	Easting	Northing	Min Distance from Flown Path to Checkpoint (Meters)
1	Course Entry Point	490.0	313.0	0.0
2	Cemetery Bend	483.0	275.0	418.4
3	Granite Pass	408.0	203.0	36.7
4	Whiskey Saddle	360.0	167.0	395.4
5	Romeo Hill	318.0	167.0	462.6
6	Hill 1161	253.0	161.0	941.0
7	Nelson Lake	204.0	202.0	5,345.5
8	McLean Lake Feed	235.0	264.0	3,421.7
9	Tri-valley Pass	308.0	293.0	2,031.9
10	Drinkwater Lake	437.0	278.0	275.5
11	Course Entry Point	490.0	313.0	2,250.5
			Average-->	1,416.3

Table 9. Subject006's Location, Direction, & Proximity Results.

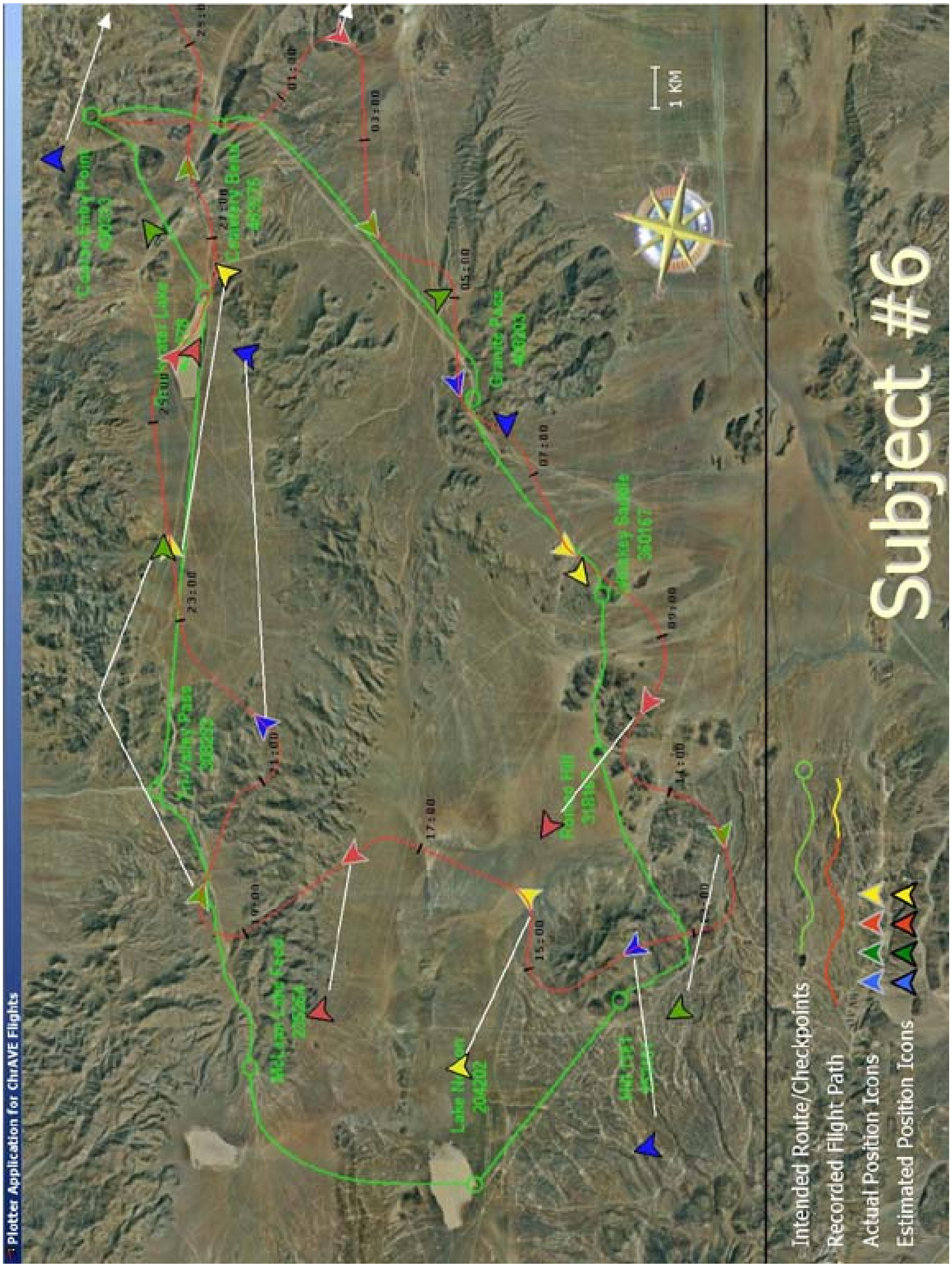

Figure 63. Subject006's Flight Path and Position Plots.

Subject007's Location, Direction, & Proximity Results

	Time	Subject's Map Plots: Easting	Subject's Map Plots: Northing	Subject's Map Plots: Heading (Grid)	Subject's VE Positions: Easting	Subject's VE Positions: Northing	Subject's VE Positions: Heading (Grid)	Difference: Distance (Meters)	Difference: Heading (Deg)
1	02:40	481.8	253.7	260.0	486.3	259.3	183.4	718.7	76.6
2	04:41	429.0	207.0	229.0	447.7	224.2	221.2	2,542.4	7.8
3	06:40	388.0	189.2	249.5	399.2	209.9	269.5	2,352.5	20.0
4	08:41	342.5	154.6	277.5	344.3	200.2	280.3	4,567.5	2.8
5	10:40	312.4	169.5	190.0	309.6	180.5	190.2	1,139.9	0.2
6	12:46	257.5	139.6	305.0	272.7	142.9	232.8	1,551.1	72.2
7	14:36	221.2	181.1	320.0	233.0	171.9	317.0	1,495.7	3.0
8	16:39	202.6	214.7	003.0	201.8	212.3	366.7	258.4	-3.7
9	18:36	220.7	255.9	083.5	216.5	255.0	078.6	425.4	4.9
10	20:35	274.9	278.1	082.0	268.3	275.7	069.8	701.5	12.2
11	22:35	315.0	288.8	090.0	322.4	287.9	091.8	741.1	1.8
12	24:33	390.7	285.9	097.5	374.5	289.9	094.3	1,673.4	3.2
13	26:43	437.0	271.3	140.0	431.1	277.1	102.0	822.5	38.0
14	28:35	477.5	304.8	080.0	478.9	291.4	082.6	1,351.3	2.6
15	30:35	493.1	283.1	250.0	498.9	272.7	265.6	1,191.1	15.6
							Averages-->	1,435.5	17.1

*Blanks indicate subject did not plot

	Check Points: Check Point Name	Check Points: Easting	Check Points: Northing	Min Distance from Flown Path to Checkpoint (Meters)
1	Course Entry Point	490.0	313.0	0.0
2	Cemetery Bend	483.0	275.0	421.6
3	Granite Pass	408.0	203.0	504.7
4	Whiskey Saddle	360.0	167.0	3,084.1
5	Romeo Hill	318.0	167.0	1,092.4
6	Hill 1161	253.0	161.0	412.9
7	Nelson Lake	204.0	202.0	118.6
8	McLean Lake Feed	235.0	264.0	208.1
9	Tri-valley Pass	308.0	293.0	534.4
10	Drinkwater Lake	437.0	278.0	31.3
11	Course Entry Point	490.0	313.0	1,723.9
			Average-->	739.3

Table 10. Subject007’s Location, Direction, & Proximity Results.

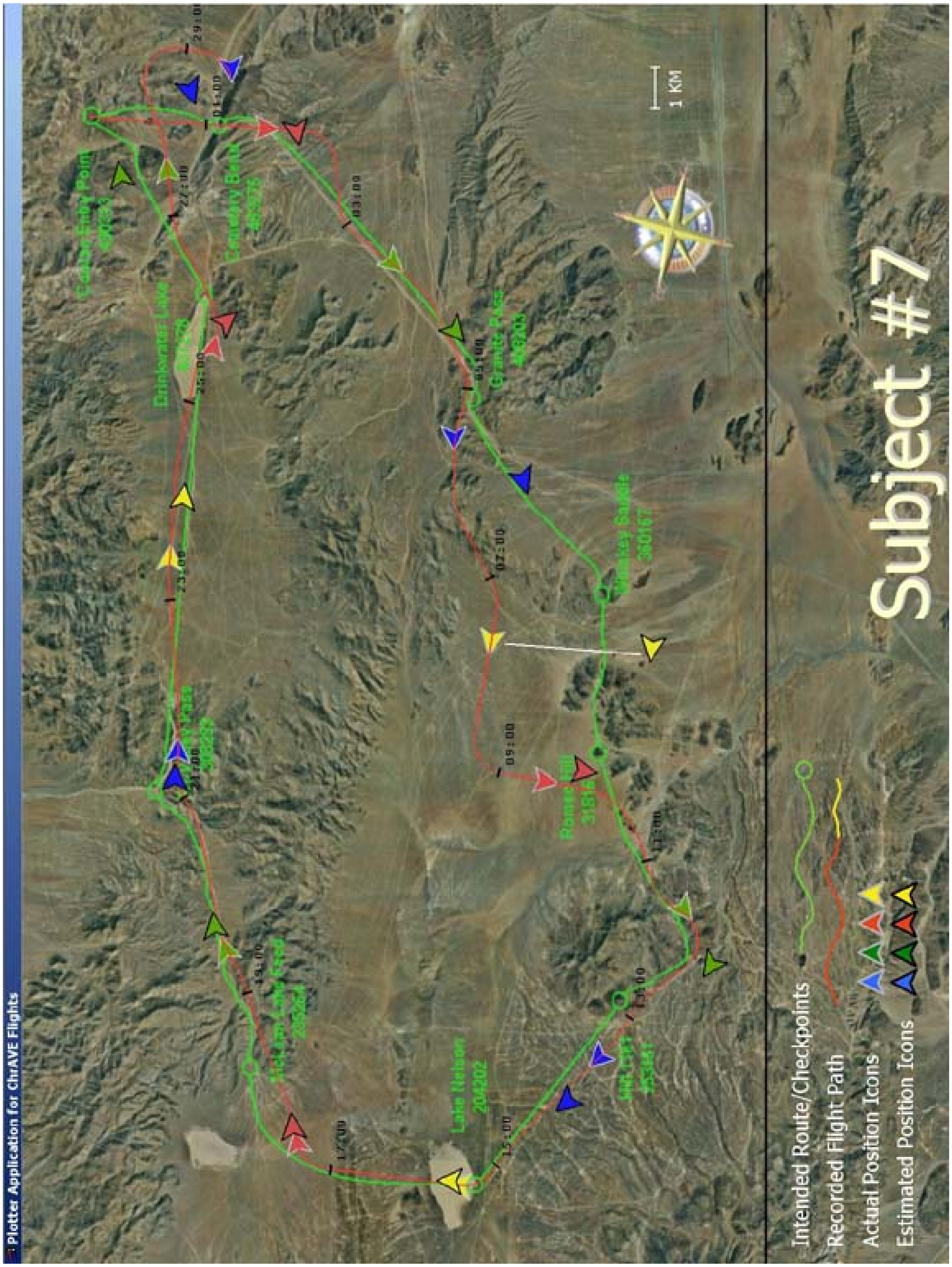

Figure 64. Subject007's Flight Path and Position Plots.

Subject008's Location, Direction, & Proximity Results

		Subject's Map Plots			Subject's VE Positions			Difference	
	Time	Easting	Northing	Heading (Grid)	Easting	Northing	Heading (Grid)	Distance (Meters)	Heading (Deg)
1	03:03	481.8	262.0	190.0	457.6	237.4	221.6	3,456.9	31.6
2	05:03								
3	08:14	362.5	170.8	218.0	381.4	184.9	216.8	2,355.2	1.2
4	10:21	326.7	169.5	269.5	335.7	153.4	255.7	1,841.8	13.8
5	12:01	270.5	148.9	270.5	294.8	143.0	255.7	2,503.6	14.8
6	14:11	255.3	160.1	349.0	255.1	163.4	008.0	326.6	19.0
7	16:09	214.9	194.0	317.5	225.4	194.0	281.7	1,054.6	35.8
8	18:08	202.0	236.0	006.0	188.9	217.7	341.9	2,251.5	24.1
9	20:08	229.0	260.8	021.0	215.3	255.4	040.8	1,476.7	19.8
10	22:07	245.7	272.3	090.0	261.6	269.0	068.6	1,622.2	21.4
11	24:06	305.0	294.1	106.0	314.4	289.7	069.0	1,039.8	37.0
12	26:07	391.2	282.7	106.2	369.8	281.6	101.3	2,144.2	4.9
13	28:07	435.0	276.1	077.8	425.1	281.7	095.3	1,136.5	17.5
14	30:07	465.2	293.2	059.5	473.2	301.4	054.0	1,145.8	5.5
15	32:09	490.2	306.8	055.0	526.9	318.6	069.5	3,859.3	14.5
							Averages-->	1,872.5	18.6

*Blanks indicate subject did not plot

	Check Points			
	Check Point Name	Easting	Northing	Min Distance from Flown Path to Checkpoint (Meters)
1	Course Entry Point	490.0	313.0	0.0
2	Cemetery Bend	483.0	275.0	394.9
3	Granite Pass	408.0	203.0	1,600.1
4	Whiskey Saddle	360.0	167.0	639.8
5	Romeo Hill	318.0	167.0	1,751.7
6	Hill 1161	253.0	161.0	192.0
7	Nelson Lake	204.0	202.0	349.4
8	McLean Lake Feed	235.0	264.0	572.5
9	Tri-valley Pass	308.0	293.0	539.8
10	Drinkwater Lake	437.0	278.0	254.3
11	Course Entry Point	490.0	313.0	32.2
			Average-->	575.2

Table 11. Subject008's Location, Direction, & Proximity Results.

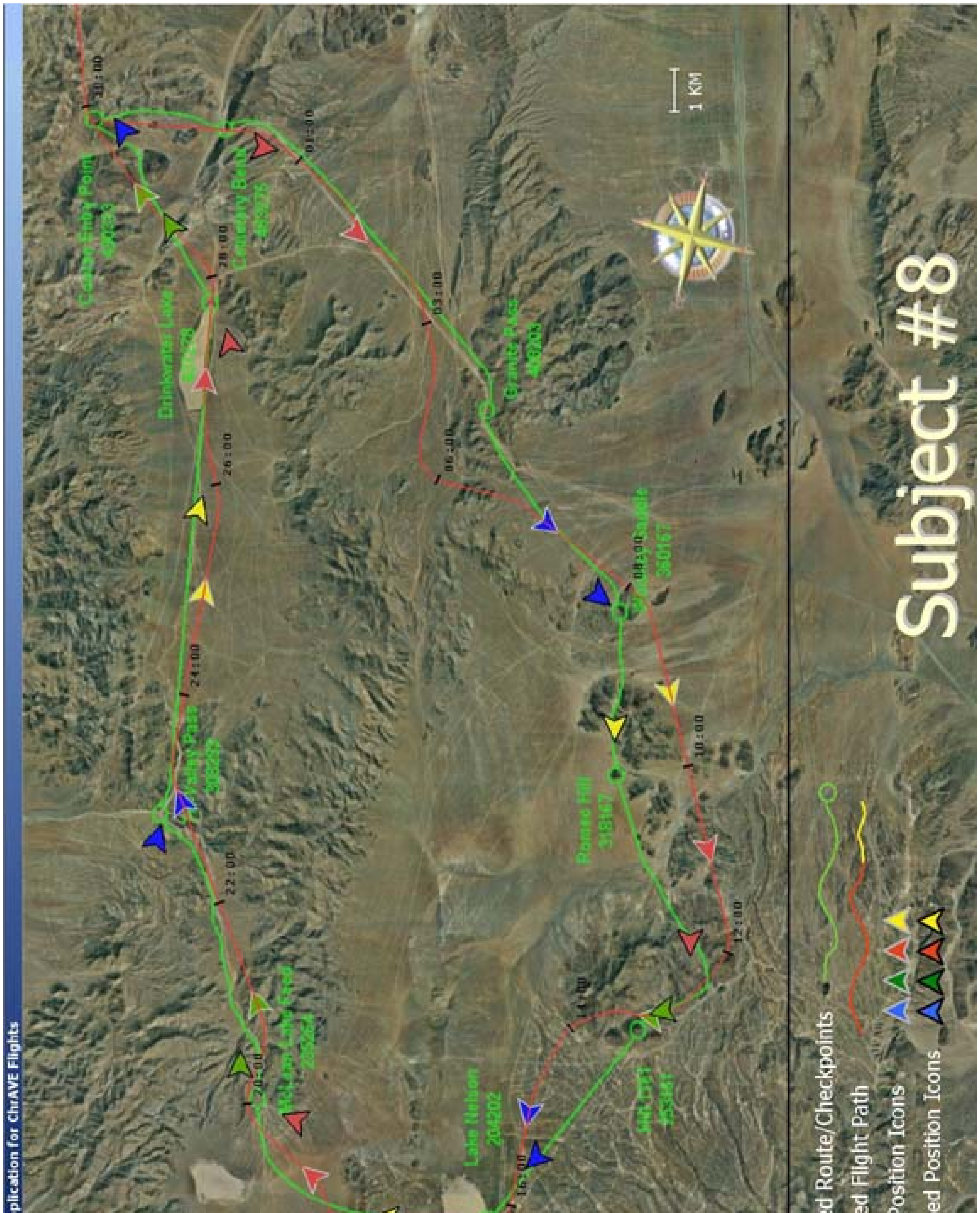

Figure 65. Subject008's Flight Path and Position Plots.

Subject009's Location, Direction, & Proximity Results

	Time	Subject's Map Plots: Easting	Subject's Map Plots: Northing	Subject's Map Plots: Heading (Grid)	Subject's VE Positions: Easting	Subject's VE Positions: Northing	Subject's VE Positions: Heading (Grid)	Difference: Distance (Meters)	Difference: Heading (Deg)
1	03:01	440.2	217.5	241.0	467.2	236.6	226.2	3,304.7	14.8
2	05:01	416.5	202.0	233.0	421.3	207.0	230.6	694.0	2.4
3	07:02	369.6	176.2	215.0	374.4	178.2	211.9	522.9	3.1
4	09:01	339.0	163.5	283.5	330.5	148.0	258.2	1,771.0	25.3
5	10:59	302.2	172.7	260.8	286.2	162.6	289.4	1,890.2	28.6
6	13:02	230.7	170.8	312.5	235.0	171.2	300.5	429.1	12.0
7	14:57	202.5	207.4	350.0	199.0	204.7	333.8	443.8	16.2
8	16:56	210.3	247.5	011.0	208.6	253.0	368.5	579.2	2.5
9	18:58	253.8	266.8	060.0	255.0	268.7	060.1	220.0	0.1
10	20:56	271.9	276.2	081.0	307.1	285.2	076.3	3,632.7	4.7
11	22:57	373.7	294.0	093.5	362.8	298.8	076.3	1,191.7	17.2
12	24:55	410.7	279.6	090.5	412.0	281.8	108.7	255.9	18.2
13	26:57	465.3	291.8	065.0	463.9	293.6	050.4	225.3	14.6
14	28:57	479.6	319.5	254.5	475.0	332.3	246.9	1,355.0	7.6
15	31:00	486.0	286.2	185.0	490.3	284.4	199.5	465.9	14.5
							Averages-->	1,132.1	12.1

*Blanks indicate subject did not plot

	Check Points: Check Point Name	Check Points: Easting	Check Points: Northing	Min Distance from Flown Path to Checkpoint (Meters)
1	Course Entry Point	490.0	313.0	0.0
2	Cemetery Bend	483.0	275.0	949.2
3	Granite Pass	408.0	203.0	204.9
4	Whiskey Saddle	360.0	167.0	297.5
5	Romeo Hill	318.0	167.0	2,119.6
6	Hill 1161	253.0	161.0	167.2
7	Nelson Lake	204.0	202.0	211.0
8	McLean Lake Feed	235.0	264.0	397.4
9	Tri-valley Pass	308.0	293.0	733.7
10	Drinkwater Lake	437.0	278.0	251.4
11	Course Entry Point	490.0	313.0	539.5
			Average-->	533.8

Table 12. Subject009's Location, Direction, & Proximity Results.

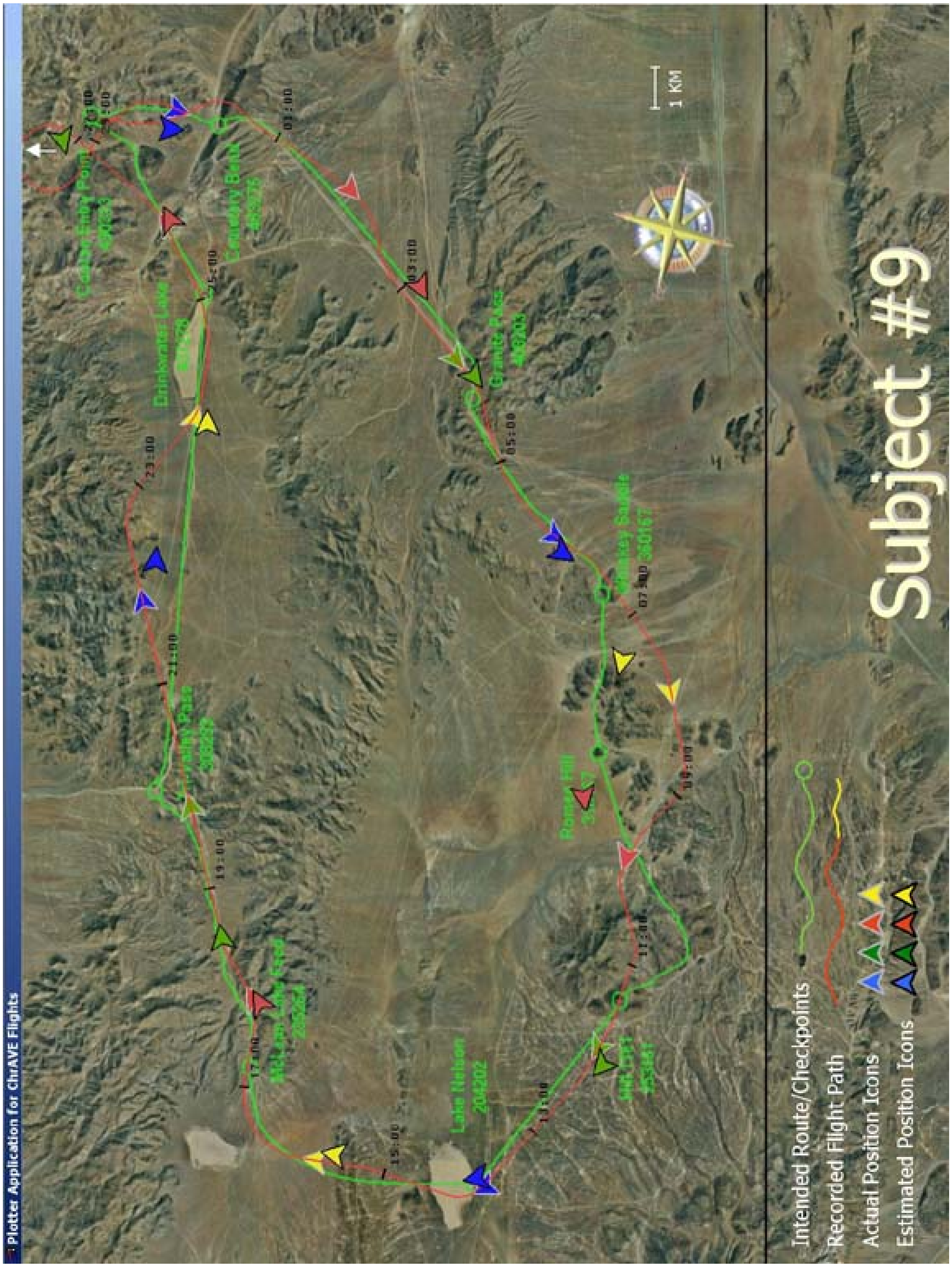

Figure 66. Subject009’s Flight Path and Position Plots.

Subject010's Location, Direction, & Proximity Results

		Subject's Map Plots			Subject's VE Positions			Difference	
	Time	Easting	Northing	Heading (Grid)	Easting	Northing	Heading (Grid)	Distance (Meters)	Heading (Deg)
1	03:02	462.7	240.1	233.0	466.3	238.9	240.1	374.6	7.1
2	04:60	417.5	203.4	201.5	422.6	207.5	246.2	652.5	44.7
3	07:00	375.5	175.3	234.0	381.4	173.7	229.5	610.3	4.5
4	08:60	328.0	172.1	273.0	328.1	169.9	271.5	218.7	1.5
5	10:57	266.8	144.0	250.0	279.8	150.5	228.6	1,452.8	21.4
6	12:57	246.9	169.7	332.0	252.8	175.8	328.0	851.1	4.0
7	14:56	208.5	199.2	301.7	209.3	200.4	288.5	150.4	13.2
8	16:56	220.1	258.9	062.0	208.0	243.6	041.9	1,951.6	20.1
9	18:57	249.5	262.8	057.0	254.0	268.5	080.7	725.8	23.7
10	20:56	301.3	273.0	018.0	306.3	282.6	055.0	1,081.1	37.0
11	22:55	393.1	275.2	078.0	357.6	293.2	091.6	3,976.6	13.6
12	24:54	408.1	282.3	140.0	409.8	286.8	129.8	476.7	10.2
13	26:55	474.0	299.9	065.0	461.0	291.0	052.2	1,576.1	12.8
14	28:55	487.5	310.7	162.0	486.1	320.4	270.9	983.1	108.9
15	30:55	481.7	268.4	154.7	489.1	268.7	157.5	742.2	2.8
							Averages-->	1,054.9	21.7

*Blanks indicate subject did not plot

	Check Points			
	Check Point Name	Easting	Northing	Min Distance from Flown Path to Checkpoint (Meters)
1	Course Entry Point	490.0	313.0	0.0
2	Cemetery Bend	483.0	275.0	461.4
3	Granite Pass	408.0	203.0	70.9
4	Whiskey Saddle	360.0	167.0	23.8
5	Romeo Hill	318.0	167.0	309.9
6	Hill 1161	253.0	161.0	261.9
7	Nelson Lake	204.0	202.0	30.3
8	McLean Lake Feed	235.0	264.0	242.8
9	Tri-valley Pass	308.0	293.0	563.9
10	Drinkwater Lake	437.0	278.0	130.0
11	Course Entry Point	490.0	313.0	456.3
			Average-->	231.9

Table 13. Subject003's Location, Direction, & Proximity Results.

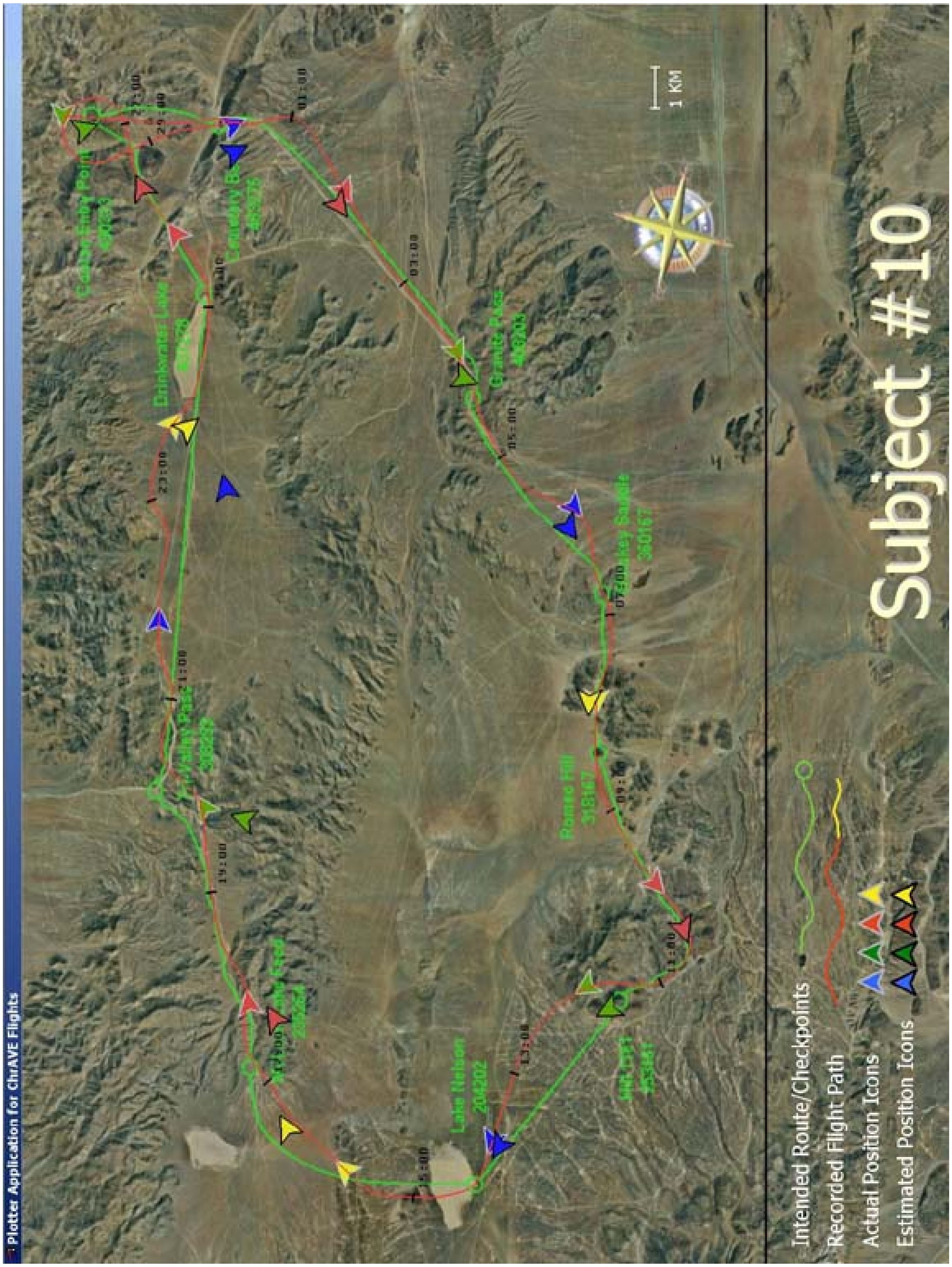

Figure 67. Subject010's Flight Path and Position Plots.

Subject011's Location, Direction, & Proximity Results

	Time	Subject's Map Plots: Easting	Northing	Heading (Grid)	Subject's VE Positions: Easting	Northing	Heading (Grid)	Difference: Distance (Meters)	Heading (Deg)
1	07:55	439.8	212.7	225.0	463.5	235.4	226.8	3,279.3	1.8
2	09:53	408.7	202.7	293.0	419.2	203.5	256.9	1,049.1	36.1
3	11:54	365.6	167.5	269.5	372.9	175.5	221.1	1,086.6	48.4
4	13:55	329.5	159.8	256.0	326.3	153.9	256.9	674.2	0.9
5	15:52	273.4	155.6	252.0	277.4	155.3	260.1	406.2	8.1
6	17:52	222.5	180.1	308.5	233.9	181.2	301.5	1,145.0	7.0
7	19:52	201.0	209.6	354.0	195.1	210.9	345.7	601.6	8.3
8	21:50	224.8	259.9	051.0	207.7	258.2	051.6	1,719.4	0.6
9	23:51	243.2	262.4	060.0	259.8	271.9	078.5	1,915.2	18.5
10	25:50	287.2	274.3	081.0	314.1	283.6	068.4	2,841.9	12.6
11	27:50	320.1	290.2	124.0	368.2	298.5	113.3	4,880.5	10.7
12	29:50	432.0	280.0	114.0	421.9	286.7	104.2	1,211.9	9.8
13	31:48	471.3	296.4	091.0	473.0	299.0	084.1	313.0	6.9
14	33:50	486.0	308.7	148.0	483.8	332.3	246.6	2,366.8	98.6
15									
							Averages-->	1,677.9	19.2

*Blanks indicate subject did not plot

	Check Point Name	Check Points: Easting	Northing	Min Distance from Flown Path to Checkpoint (Meters)
1	Course Entry Point	490.0	313.0	0.0
2	Cemetery Bend	483.0	275.0	478.9
3	Granite Pass	408.0	203.0	59.7
4	Whiskey Saddle	360.0	167.0	245.0
5	Romeo Hill	318.0	167.0	1,464.7
6	Hill 1161	253.0	161.0	211.0
7	Nelson Lake	204.0	202.0	209.5
8	McLean Lake Feed	235.0	264.0	674.1
9	Tri-valley Pass	308.0	293.0	1,101.9
10	Drinkwater Lake	437.0	278.0	476.1
11	Course Entry Point	490.0	313.0	283.1
			Average-->	473.1

Table 14. Subject011's Location, Direction, & Proximity Results.

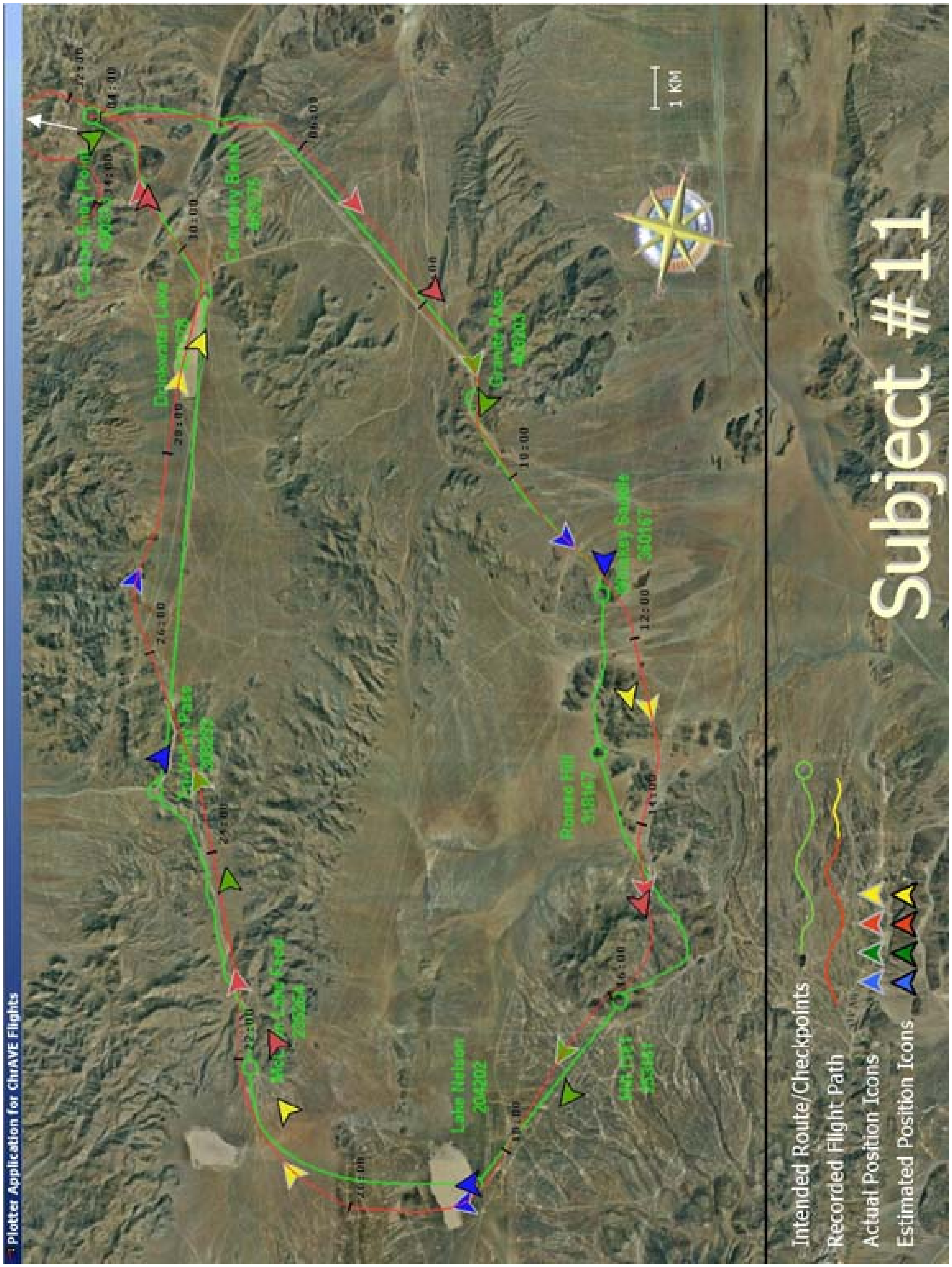

Figure 68. Subject011's Flight Path and Position Plots.

Subject012's Location, Direction, & Proximity Results

	Subject's Map Plots				Subject's VE Positions			Difference	
	Time	Easting	Northing	Heading (Grid)	Easting	Northing	Heading (Grid)	Distance (Meters)	Heading (Deg)
1	02:47	464.4	241.2	264.0	468.0	242.8	256.1	392.5	7.9
2	04:46	411.1	204.3	292.5	425.7	210.1	251.9	1,570.0	40.6
3	06:51	390.2	184.7	276.0	386.2	168.3	238.2	1,691.1	37.8
4	08:48	325.9	140.2	231.0	344.5	148.9	250.0	2,051.6	19.0
5	10:49	281.5	157.6	252.0	300.2	160.1	286.1	1,889.8	34.1
6	12:46	251.8	151.2	339.0	254.2	146.6	317.6	518.9	21.4
7	14:43	212.5	192.0	319.0	226.6	186.5	305.0	1,507.7	14.0
8	16:43	200.0	225.0	008.0	197.5	225.3	353.9	252.4	14.1
9	18:43	228.1	261.4	064.5	215.3	268.3	056.2	1,454.0	8.3
10	20:46	273.5	270.0	083.0	271.4	273.8	068.7	439.2	14.3
11	22:42	296.5	308.0	052.0	313.0	309.4	042.8	1,656.7	9.2
12	24:42	346.2	289.5	101.0	339.5	276.6	140.4	1,448.0	39.4
13	26:43	397.0	277.5	082.5	395.9	266.8	094.5	1,073.7	12.0
14	28:43	447.0	281.5	061.5	447.3	285.0	056.0	353.4	5.5
15	30:22	481.6	297.5	089.0	488.4	299.4	102.9	709.6	13.9
							Averages-->	1,133.9	19.4

*Blanks indicate subject did not plot

	Check Points			
	Check Point Name	Easting	Northing	Min Distance from Flown Path to Checkpoint (Meters)
1	Course Entry Point	490.0	313.0	0.0
2	Cemetery Bend	483.0	275.0	472.1
3	Granite Pass	408.0	203.0	240.5
4	Whiskey Saddle	360.0	167.0	60.7
5	Romeo Hill	318.0	167.0	1,653.0
6	Hill 1161	253.0	161.0	604.2
7	Nelson Lake	204.0	202.0	253.2
8	McLean Lake Feed	235.0	264.0	726.4
9	Tri-valley Pass	308.0	293.0	694.1
10	Drinkwater Lake	437.0	278.0	75.1
11	Course Entry Point	490.0	313.0	1,363.4
			Average-->	558.4

Table 15. Subject012’s Location, Direction, & Proximity Results.

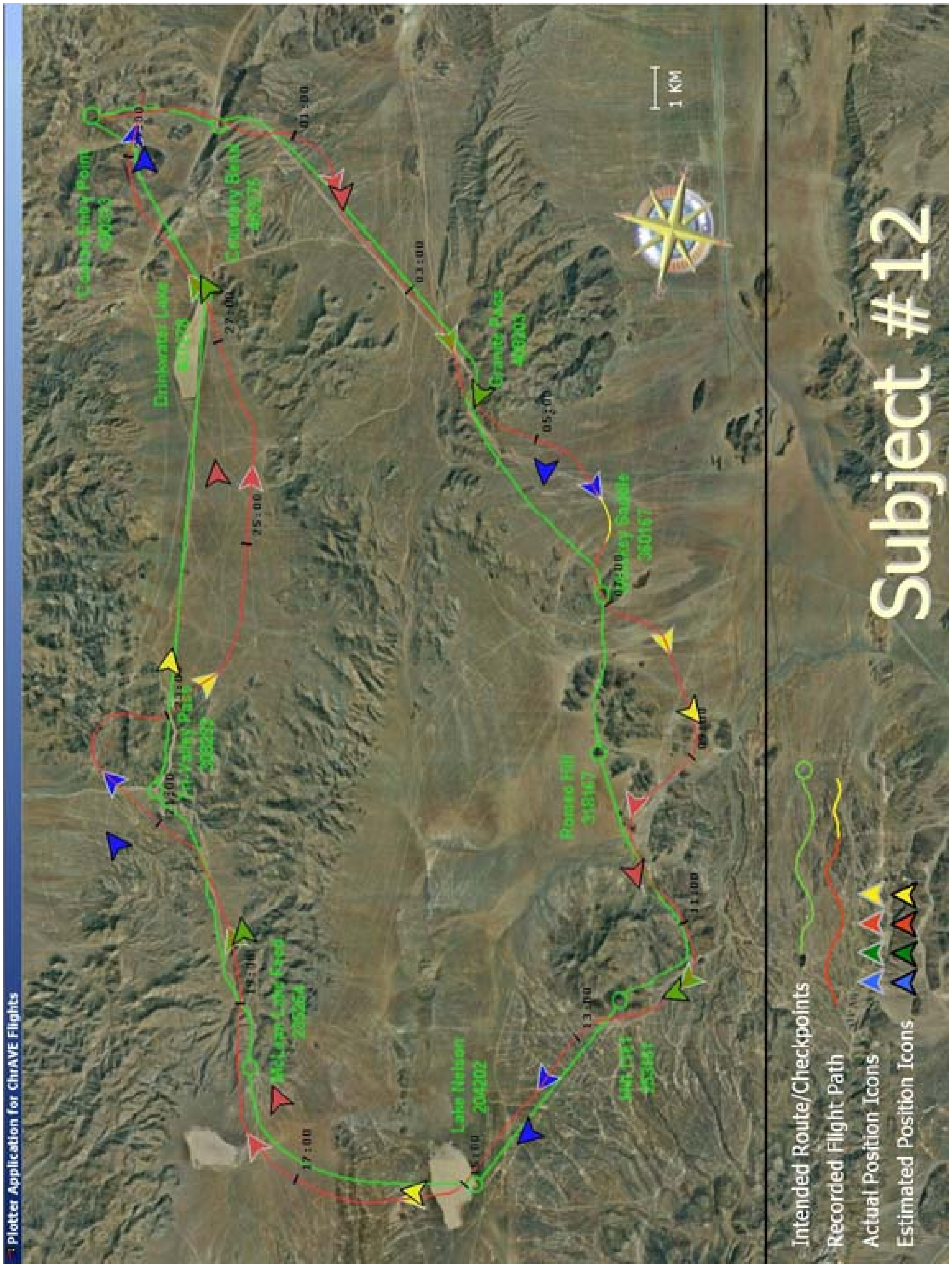

Figure 69. Subject012’s Flight Path and Position Plots.

Subject013's Location, Direction, & Proximity Results

		Subject's Map Plots			Subject's VE Positions			Difference	
	Time	Easting	Northing	Heading (Grid)	Easting	Northing	Heading (Grid)	Distance (Meters)	Heading (Deg)
1	02:60	472.3	243.7	228.0	462.7	239.2	227.0	1,059.1	1.0
2	05:00	418.0	198.1	235.0	420.9	202.3	250.9	506.1	15.9
3	07:01	367.2	166.6	261.0	373.2	175.8	239.9	1,094.5	21.1
4	09:03	317.5	162.8	266.0	323.8	161.0	258.8	653.2	7.2
5	11:02	283.0	149.3	261.0	277.3	167.2	296.6	1,881.3	35.6
6	12:59	204.7	193.1	352.5	232.1	185.5	293.6	2,843.5	58.9
7	14:58	218.0	260.0	060.0	209.1	224.9	023.2	3,621.9	36.8
8	16:57	231.5	267.2	093.5	246.4	265.0	049.0	1,501.7	44.5
9	18:57	250.2	274.9	080.0	266.4	309.6	351.4	3,828.0	88.6
10	20:56	299.1	293.1	106.0	296.6	308.3	153.4	1,539.0	47.4
11	22:58	341.2	292.0	100.0	339.1	270.7	124.9	2,139.1	24.9
12	24:56	401.7	273.7	069.0	390.2	274.8	072.9	1,154.6	3.9
13	26:54	455.0	292.5	048.0	441.5	295.1	052.0	1,379.4	4.0
14	28:58	486.0	314.5	104.8	484.8	317.6	161.5	330.7	56.7
15	30:58	482.3	257.5	231.0	484.7	259.0	216.4	281.9	14.6
							Averages-->	1,587.6	30.7

*Blanks indicate subject did not plot

	Check Points			
	Check Point Name	Easting	Northing	Min Distance from Flown Path to Checkpoint (Meters)
1	Course Entry Point	490.0	313.0	0.0
2	Cemetery Bend	483.0	275.0	466.0
3	Granite Pass	408.0	203.0	204.2
4	Whiskey Saddle	360.0	167.0	129.4
5	Romeo Hill	318.0	167.0	704.2
6	Hill 1161	253.0	161.0	1,598.9
7	Nelson Lake	204.0	202.0	639.9
8	McLean Lake Feed	235.0	264.0	670.1
9	Tri-valley Pass	308.0	293.0	334.3
10	Drinkwater Lake	437.0	278.0	1,122.6
11	Course Entry Point	490.0	313.0	476.7
			Average-->	576.9

Table 16. Subject013's Location, Direction, & Proximity Results.

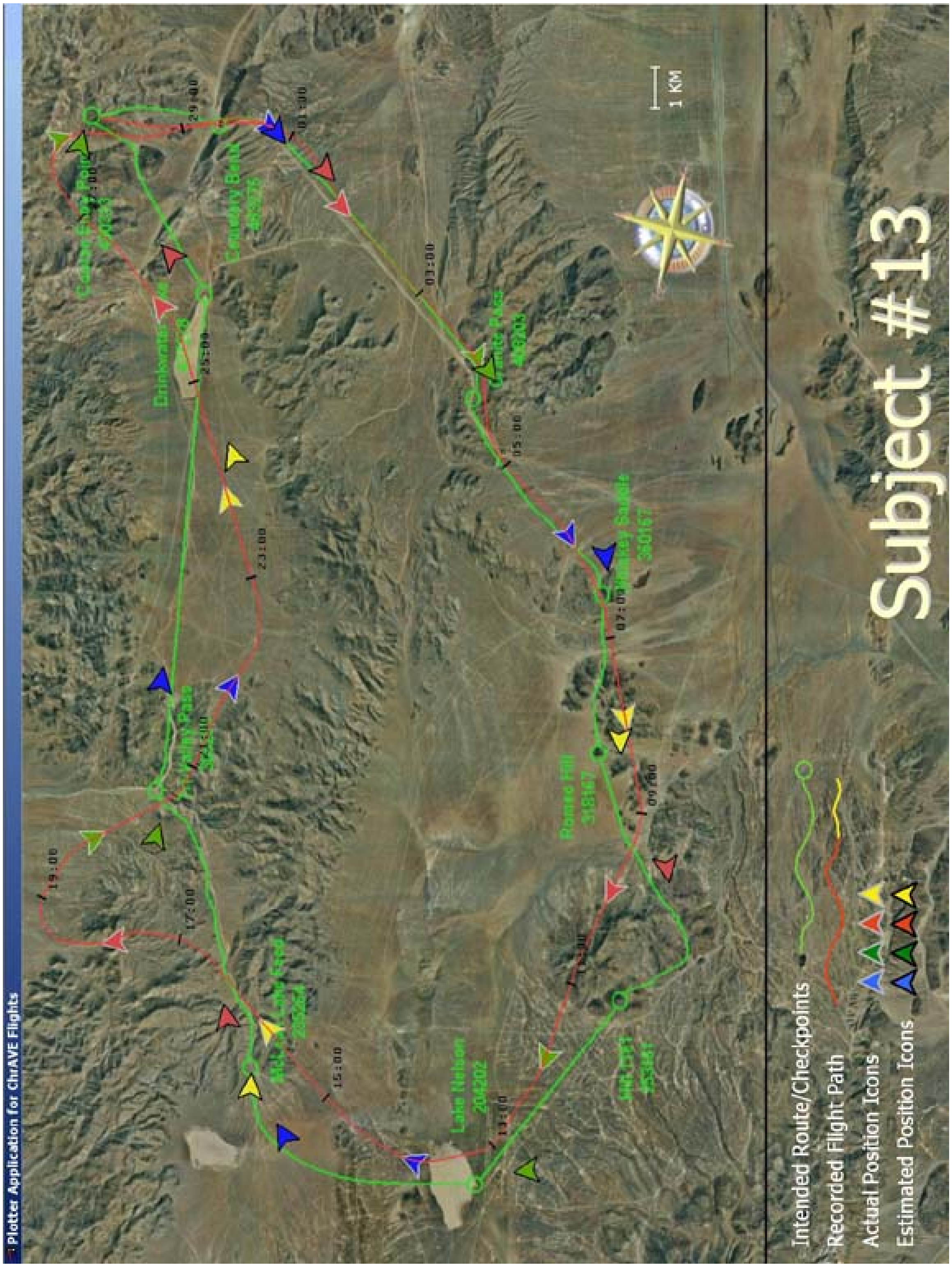

Figure 70. Subject013's Flight Path and Position Plots.

Subject014's Location, Direction, & Proximity Results

		Subject's Map Plots			Subject's VE Positions			Difference	
	Time	Easting	Northing	Heading (Grid)	Easting	Northing	Heading (Grid)	Distance (Meters)	Heading (Deg)
1	02:56	458.7	231.5	233.0	464.5	240.1	235.0	1,038.9	2.0
2	04:55	420.3	200.7	250.0	422.0	206.3	245.0	583.0	5.0
3	06:55	380.6	180.6	227.0	375.1	175.1	228.3	778.5	1.3
4	08:56	339.2	159.2	220.0	324.5	146.1	226.0	1,972.7	6.0
5	10:53	290.7	146.9	298.0	283.8	146.0	310.6	692.3	12.6
6	12:54	237.5	175.3	311.0	240.6	176.0	304.0	316.9	7.0
7	14:52	202.5	204.7	332.5	202.0	204.1	340.5	77.9	8.0
8	16:51	218.0	253.7	049.0	210.4	252.4	037.0	771.2	12.0
9	18:51	253.7	269.9	109.0	257.6	277.5	107.7	854.2	1.3
10	20:50	305.0	286.2	068.0	310.4	285.0	076.6	553.4	8.6
11	22:52	377.5	289.4	093.0	366.2	287.8	093.1	1,145.1	0.1
12	24:50	418.1	277.6	094.0	420.0	280.8	095.2	369.6	1.2
13	26:50	471.7	299.9	064.0	472.0	297.3	050.8	258.5	13.2
14	28:51	495.0	294.5	177.0	510.9	317.5	177.6	2,798.5	0.6
15	30:50	522.3	267.7	294.0	512.6	269.7	266.2	990.3	27.8
							Averages-->	880.1	7.1

*Blanks indicate subject did not plot

	Check Points			
	Check Point Name	Easting	Northing	Min Distance from Flown Path to Checkpoint (Meters)
1	Course Entry Point	490.0	313.0	0.0
2	Cemetery Bend	483.0	275.0	711.9
3	Granite Pass	408.0	203.0	296.7
4	Whiskey Saddle	360.0	167.0	403.9
5	Romeo Hill	318.0	167.0	2,082.7
6	Hill 1161	253.0	161.0	280.9
7	Nelson Lake	204.0	202.0	77.3
8	McLean Lake Feed	235.0	264.0	380.5
9	Tri-valley Pass	308.0	293.0	835.3
10	Drinkwater Lake	437.0	278.0	120.1
11	Course Entry Point	490.0	313.0	104.2
			Average-->	481.2

Table 17. Subject014's Location, Direction, & Proximity Results.

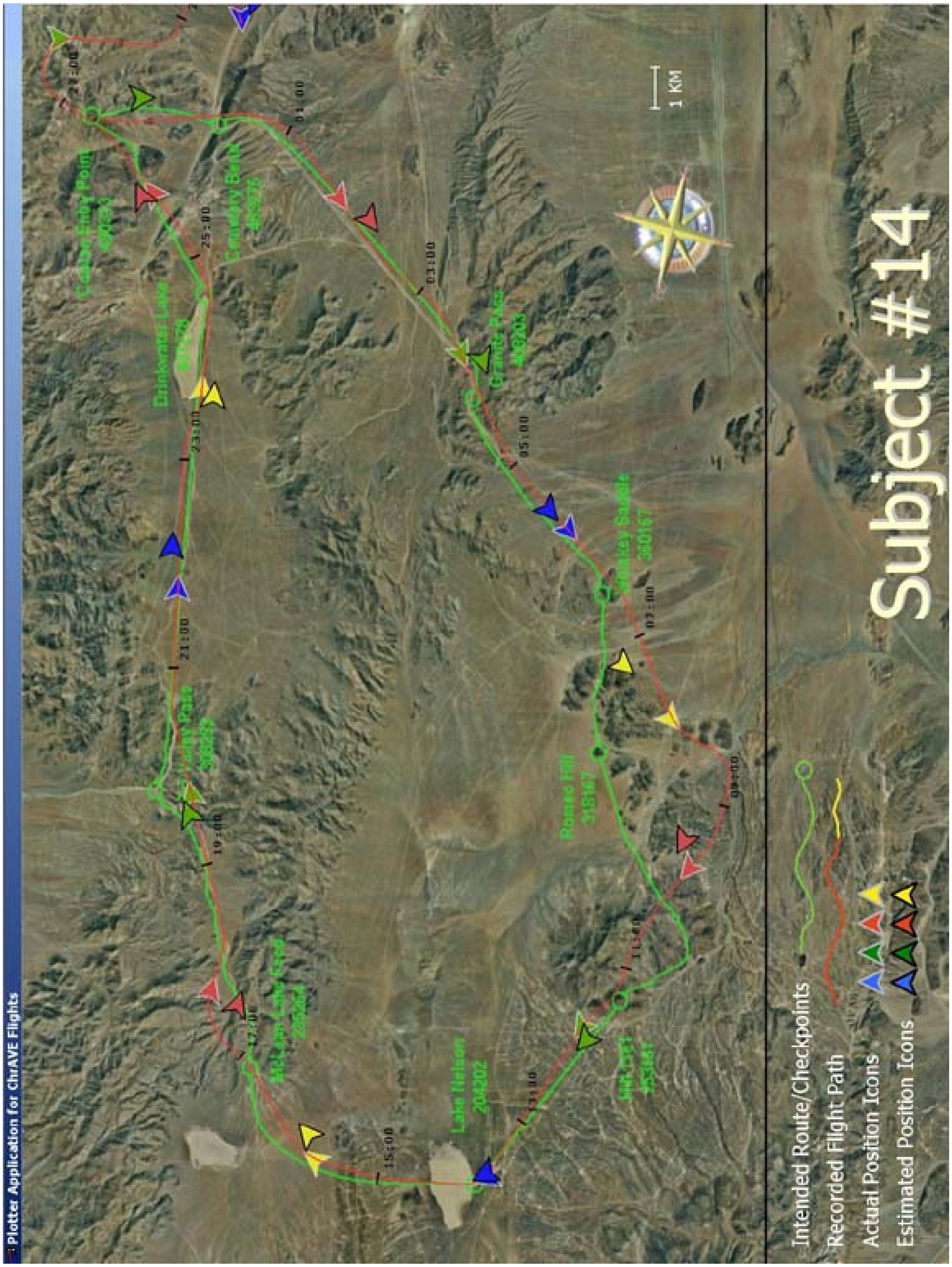

Figure 71. Subject014's Flight Path and Position Plots.

Subject015's Location, Direction, & Proximity Results

	Subject's Map Plots				Subject's VE Positions			Difference	
	Time	Easting	Northing	Heading (Grid)	Easting	Northing	Heading (Grid)	Distance (Meters)	Heading (Deg)
1	02:58	462.5	243.7	211.0	464.1	243.6	232.0	160.4	21.0
2	04:57	415.2	206.4	237.0	416.6	207.7	238.6	190.3	1.6
3	06:58	375.1	176.3	238.0	372.2	171.9	225.3	527.0	12.7
4	08:58	337.2	164.5	271.0	322.8	155.1	266.0	1,715.7	5.0
5	10:55	311.2	158.8	307.0	277.3	166.6	265.3	3,480.3	41.7
6	12:56	232.8	161.1	252.0	230.8	154.9	262.8	648.6	10.8
7	14:54	199.1	195.1	025.0	200.7	190.4	340.9	496.7	44.1
8	16:54	211.7	243.1	016.0	188.0	239.6	351.6	2,396.9	24.4
9	18:55	227.3	265.6	083.5	220.2	269.9	084.5	828.0	1.0
10	20:52	261.8	273.0	075.0	276.2	276.4	075.8	1,478.1	0.8
11	22:52	320.5	293.6	114.0	327.7	293.0	104.3	719.3	9.7
12	24:52	387.3	282.7	094.0	378.0	269.6	120.1	1,603.7	26.1
13	26:52	431.2	268.7	049.0	429.4	267.4	060.0	227.2	11.0
14	28:54	463.7	279.4	091.0	480.6	286.3	068.7	1,826.9	22.3
15	30:52	500.2	321.3	038.0	502.4	333.9	356.9	1,283.4	41.1
							Averages-->	1,172.2	18.2

*Blanks indicate subject did not plot

	Check Points			
	Check Point Name	Easting	Northing	Min Distance from Flown Path to Checkpoint (Meters)
1	Course Entry Point	490.0	313.0	0.0
2	Cemetery Bend	483.0	275.0	460.0
3	Granite Pass	408.0	203.0	53.2
4	Whiskey Saddle	360.0	167.0	380.0
5	Romeo Hill	318.0	167.0	1,218.9
6	Hill 1161	253.0	161.0	362.6
7	Nelson Lake	204.0	202.0	693.7
8	McLean Lake Feed	235.0	264.0	726.2
9	Tri-valley Pass	308.0	293.0	755.5
10	Drinkwater Lake	437.0	278.0	538.5
11	Course Entry Point	490.0	313.0	1,184.7
			Average-->	579.4

Table 18. Subject015's Location, Direction, & Proximity Results.

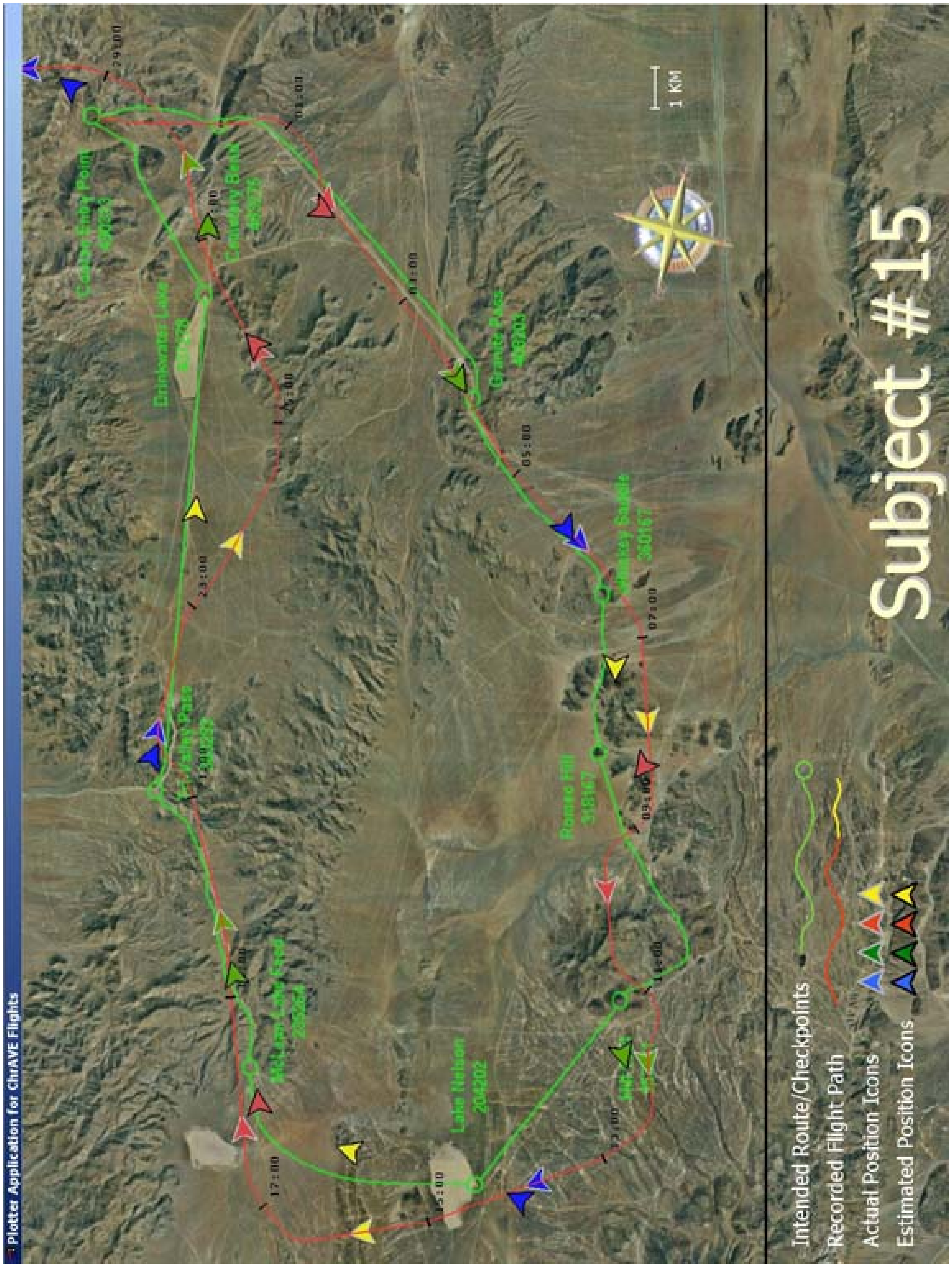

Figure 72. Subject015's Flight Path and Position Plots.

A survey, in the form of a questionnaire (Appendix A), was conducted to gather data and information on acceptable low-level navigation criteria and priorities.

Additionally, physiology tests were conducted on each subject with the headgear off and on.

1. Visual acuity-intended to show the degradation in the ability to read writing on the map while hooded.

2. Color identification-intended to show the degradation in the ability to correctly perceive colors on the map while hooded.

3. Dvorine psudo-isochromatic plates-intended to determine the extent to which the ChrAVE introduces color blindness to subjects wearing the HMD.

4. Hand-eye coordination test-intended to show the degradation in the ability to interact physically with the real world while hooded.

Refer to figure 36 to view the results of the physiology tests.

APPENDIX D. PEER EVALUATIONS

	Location, Direction, & Proximity Result Averages				Peer Evaluations		
	Position & Orientation Differences		Checkpoint Proximities				
Subject	Distance (Meters)	Heading (Deg)	Min Distance from Flown Path to Checkpoint (Meters)	Number of Acceptable Checkpoint Proximities *4	Average Proximity of Paths Score *1	Average Location Estimation Score *2	Total Acceptable Overall Performance Ratings *3
001	1,124.9	14.4	378.1	4	2.4	1.9	14
002	965.5	21.7	326.7	5	1.8	2.1	14
003	2,543.6	32.9	1346.0	1	6.3	5.5	0
004	2,403.2	30.0	1279.9	4	4.9	4.9	5
005	1,521.1	26.8	924.1	4	3.8	3.5	12
006	4,586.1	28.1	1416.3	1	6.6	6.4	0
007	1,435.5	17.1	739.3	3	3.5	3.4	13
008	1,872.5	18.6	575.2	3	3.4	3.6	14
009	1,132.1	12.1	533.8	4	2.7	2.5	14
010	1,054.9	21.7	231.9	5	1.8	2.2	14
011	1,677.9	19.2	473.1	4	2.3	2.8	14
012	1,133.9	19.4	558.4	4	3.7	3.1	14
013	1,587.6	30.7	576.9	2	4.7	3.8	7
014	880.1	7.1	481.2	3	2.6	2.1	14
015	1,172.2	18.2	579.4	1	4.1	3.5	10
Averages->	1,672.7	21.2	694.7	3.2	3.6	3.4	10.6

*1. The subject's ability to maintain a flight path in acceptable proximity to the intended path.
- Rated using a 1 to 7 scale, '1' indicating highly acceptable while '7' indicates not acceptable.
- This criteria is independent of the following criteria, meaning the proximity to the intended flight path was evaluated independently of whether or not the subject knew where they were.

*2. The subject's ability to correctly estimate their location.
- Rated using a 1 to 7 scale, '1' indicating highly acceptable while '7' indicates not acceptable.
- This criteria is independent of the preceding criteria, meaning the accuracy of the position estimation was to be evaluated independently of whether or not the subjects were on the intended route.

*3. The overall performance.
- Rated the overall performance as acceptable or not acceptable ('A' or 'N')

*4. Number of checkpoints flown within the subject pool's 260 meter threshold as established by question #22 of the questionnaire.

Table 19. Summary of subject pools empirical data and peer evaluations.

		PROXIMITY OF PATHS EVALUATIONS																
	Subject Number	001	002	003	004	005	006	007	008	009	010	011	012	013	014	015	Average Grade	Harshness Ranking
EVALUATORS	Subject 001		2	6	5	4	7	3	3	3	2	2	3	4	3	4	3.642857	7
	Subject 002	3		7	7	5	7	4	4	3	2	3	4	6	3	4	4.428571	2
	Subject 003	3	3		4	4	6	4	3	3	3	3	4	4	3	4	3.642857	7
	Subject 004	2	2	6		4	6	4	3	2	1	2	2	4	2	3	3.071429	12
	Subject 005	2	1	5	4		7	2	3	2	1	1	3	4	2	4	2.928571	13
	Subject 006	2	1	7	4	3		3	2	3	2	2	3	4	2	3	2.928571	13
	Subject 007	3	2	6	5	4	7		5	3	2	3	5	6	4	5	4.285714	3
	Subject 008	1	1	7	4	3	7	4		3	1	1	4	5	2	4	3.357143	10
	Subject 009	3	3	7	6	5	7	5	5		2	2	5	6	2	6	4.571429	1
	Subject 010	3	1	6	3	3	6	3	3	2		3	3	5	2	4	3.357143	10
	Subject 011	3	3	6	4	4	7	3	3	3	2		4	5	2	5	3.857143	6
	Subject 012	1	1	5	5	2	6	2	3	2	1	2		4	3	4	2.928571	13
	Subject 013	3	2	7	6	4	7	4	3	3	2	3	4		3	4	3.928571	5
	Subject 014	3	2	7	6	4	7	4	4	3	2	2	4	5		4	4.071429	4
	Subject 015	2	1	6	5	4	6	4	3	3	2	3	4	4	3		3.571429	9
	Average	2.43	1.79	6.29	4.86	3.79	6.64	3.50	3.36	2.71	1.79	2.29	3.71	4.71	2.57	4.14		
	Rank	4	1	14	13	10	15	8	7	6	1	3	9	12	5	11		

		LOCATION ESTIMATION EVALUATIONS																
	Subject Number	001	002	003	004	005	006	007	008	009	010	011	012	013	014	015	Average Grade	Harshness Ranking
EVALUATORS	Subject 001		2	5	5	4	7	4	4	3	2	3	3	4	2	3	3.642857	5
	Subject 002	2		7	7	3	7	4	4	3	2	3	2	3	2	3	3.714286	4
	Subject 003	3	3		5	4	6	4	4	3	2	3	3	4	3	3	3.571429	7
	Subject 004	1	4	4		3	6	2	4	1	1	1	2	3	2	2	2.571429	15
	Subject 005	2	2	5	4		7	2	3	2	2	2	2	4	1	4	3	12
	Subject 006	1	2	6	5	4		3	2	2	3	4	4	4	2	3	3.214286	10
	Subject 007	2	2	6	5	4	7		6	3	3	3	4	5	2	5	4.071429	2
	Subject 008	1	1	6	4	2	7	2		2	1	2	2	4	1	3	2.714286	14
	Subject 009	3	2	6	5	4	6	5	5		4	3	4	4	2	5	4.142857	1
	Subject 010	2	1	5	4	3	6	3	3	3		4	4	3	2	4	3.357143	9
	Subject 011	2	2	5	4	5	6	4	3	3	2		3	4	2	5	3.571429	7
	Subject 012	1	1	5	6	2	6	3	3	2	1	2		4	2	2	2.857143	13
	Subject 013	2	2	6	5	4	6	4	3	3	3	3	4		3	3	3.642857	5
	Subject 014	2	3	7	6	4	7	4	4	2	3	3	3	4		4	4	3
	Subject 015	2	2	4	4	3	6	4	3	3	2	3	3	3	3		3.214286	10
	Average	1.86	2.07	5.50	4.93	3.50	6.43	3.43	3.64	2.50	2.21	2.79	3.07	3.79	2.07	3.50		
	Rank	1	2	14	13	9	15	8	11	5	4	6	7	12	2	9		

		OVERALL PERFORMANCE EVALUATIONS																
	Subject Number	001	002	003	004	005	006	007	008	009	010	011	012	013	014	015	Average Grade	Harshness Ranking
EVALUATORS	Subject 001		1	0	0	1	0	1	1	1	1	1	1	1	1	1	0.785714	7
	Subject 002	1		0	0	1	0	1	1	1	1	1	1	0	1	1	0.714286	9
	Subject 003	1	1		0	1	0	1	1	1	1	1	1	1	1	1	0.857143	1
	Subject 004	1	1	0		1	0	1	1	1	1	1	1	1	1	1	0.857143	1
	Subject 005	1	1	0	1		0	1	1	1	1	1	1	1	1	1	0.857143	1
	Subject 006	1	1	0	0	1		1	1	1	1	1	1	1	1	1	0.857143	1
	Subject 007	1	1	0	1	1	0		1	1	1	1	1	1	1	1	0.857143	1
	Subject 008	1	1	0	1	1	0	1		1	1	1	1	0	1	1	0.785714	7
	Subject 009	1	1	0	0	1	0	1	1		1	1	1	0	1	0	0.642857	13
	Subject 010	1	1	0	1	1	0	1	1	1		1	1	0	1	0	0.714286	9
	Subject 011	1	1	0	0	0	0	1	1	1	1		1	0	1	0	0.571429	14
	Subject 012	1	1	0	0	1	0	1	1	1	1	1		0	1	1	0.714286	9
	Subject 013	1	1	0	0	0	0	0	1	1	1	1	1		1	0	0.571429	14
	Subject 014	1	1	0	0	1	0	1	1	1	1	1	1	0		1	0.714286	9
	Subject 015	1	1	0	1	1	0	1	1	1	1	1	1	1	1		0.857143	1
	Sum	14.00	14.00	0.00	5.00	12.00	0.00	13.00	14.00	14.00	14.00	14.00	14.00	7.00	14.00	10.00		
	Average	1.00	1.00	0.00	0.36	0.86	0.00	0.93	1.00	1.00	1.00	1.00	1.00	0.50	1.00	0.71		
	Rank	1	1	14	13	10	14	9	1	1	1	1	1	12	1	11		

Table 20. Subject pool's peer evaluations.

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